TECHNICAL REPORT H-77-13

RED RIVER WATERWAY, LA., TEX., ARK., AND OKLA., MISSISSIPPI RIVER TO SHREVEPORT, LA., REACH, LOCK AND DAM NO. 1

Hydraulic Model Investigation

by

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Tests were conducted on a 1:36-scale model of the Red River Spillway No. 1 to develop a conventional jump-type stilling basin and plans of riprap that would provide adequate protection of the approach and exit channels for emergency (single-gated flows) and normal operating conditions. The spillway consists of a 550-ft length of broad-crested weir controlled by eleven 31-ft-high and 50-ft-wide tainter gates. The original design stilling basin downstream of a spillway with a crest elevation of 4.0 ft did not perform satisfactorily for the
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single-gate operation. A 6-ft lower (el -20) and 20-ft longer (100 ft total) stilling basin apron with two rows of 10-ft-high by 7-ft-wide baffles and 45-ft-long pier extensions was necessary to provide adequate energy dissipation. Two other stilling basin designs were developed for higher spillway crest elevations of 8 and 11 ft to provide satisfactory flow conditions for both normal and emergency operating conditions. During the course of study, approach elevations of 6, 8, and 11 ft were tested to reveal the effects on the spillway efficiency and tests were conducted with runaway barges to determine if a loose barge loaded to a 9-ft draft could be flushed through the stilling basins. Tests to determine the minimum riprap protection for the exit channel bottom indicated a 300-ft length of protection is required downstream of the basin. A series of tests to determine discharge characteristics revealed that data from a previous model investigation could be used to obtain the discharge coefficients of the Red River spillways, and comparison plots are provided in this report.

PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers (OCE), and the U. S. Army Engineer Division, Lower Mississippi Valley (LMVD), in the 2d and 1st indorsements, respectively, to the U. S. Army Engineer District, New Orleans (LMN), request letter dated 22 May 1972.

The study was conducted intermittently in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) from October 1972 to June 1974 under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and Mr. J. L. Grace, Jr., Chief of the Structures Division, and under the supervision of Mr. G. A. Pickering, Chief of the Locks and Conduits Branch. The engineer in immediate charge of the model was Mr. N. R. Oswalt, who was assisted by Messrs. H. H. Allen, C. L. Dent, and W. A. Walker. This report was prepared by Mr. Oswalt.

During the course of the investigation, LMN personnel Messrs. Jack Bardwell, Ira Moss, John Williams, Marcial Facio, Bill Garrett, Max Lamb, and Larry Cook (the latter two presently of LMVD), LMVD personnel Messrs. Rodney Resta, Bill Hill, and Estes Walker, and Mr. J. P. Davis (retired) and Mr. Sam Powell of OCE visited WES to observe model operation and discuss results.

Directors of WES during the conduct of the tests and the preparation and publication of this report were BG E. D. Peixotto, CE, COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	0.0254	metres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
feet per second	0.3048	metres per second
cubic feet per second	0.02831685	cubic metres per second

RED RIVER WATERWAY, LA., TEX., ARK., AND OKLA., MISSISSIPPI RIVER TO SHREVEPORT, LA., REACH LOCK AND DAM NO. 1

Hydraulic Model Investigation

PART I: INTRODUCTION

Location of Project

1. The Red River Waterway Project consists of four distinct reaches: (a) Mississippi River to Shreveport, Louisiana; (b) Shreveport, Louisiana, to Daingerfield, Texas; (c) Shreveport, Louisiana, to Index, Arkansas; and (d) Index, Arkansas, to Densison Dam, Texas. Only the first reach (Figure 1) and the first upstream spillway are pertinent to this report. Within the first reach, the plan provides for establishing a navigable channel approximately 227 miles* long and 9 ft deep

Figure 1. Vicinity map

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

by 200 ft wide from the Mississippi River to Shreveport via the Old and Red Rivers and construction of a system of five locks and dams. The lock dimensions will be 84 ft (wide) and 685 ft (usable chamber length). Red River Lock and Dam No. 1 (hereinafter referred to as Spillway No. 1) will be located at channel mile 43.2 from the mouth of the realigned Red River channel. The axis of the dam will be approximately 0.9 realigned miles upstream from the 1967 river mile 42.9 in Catahoula Parish, Louisiana. The location of the project is shown in Figures 1 and 2.

Pertinent Project Features

2. The principal structures associated with Red River Spillway No. 1 will consist of a navigation lock, a gated spillway, and concrete abutment walls. The lock, with nominal chamber dimensions of 84 by 785 ft, pintle to pintle, will be on the left riverbank looking downstream. The lift will vary up to a maximum of 36 ft depending on the downstream Mississippi River stages.

3. The navigation dam will contain eleven 31-ft-high by 50-ft-wide tainter gates mounted between 9-ft-wide piers. The gate sill will be at el 11.0* and the tops of the gates, when closed, will be at el 42.0 and will provide a 2-ft freeboard above the normal upper pool elevation of 40.0. The adjacent channel bottom upstream of the dam will be at el 6.0 and at el -11.0 downstream of the stilling basin. The net width of the dam is 550 ft and the gross width of the abutments from face to face is 640 ft. Plate 1 shows an elevation view of the spillway and stilling basin portion of the dam.

Purpose of Model Investigation

4. Hydraulic model tests were conducted to assist in the development of satisfactory stilling basin designs and riprap protection plans for the conditions of one gate one-half and fully open and subject to normal pool and minimum tailwater elevations. Also, the model provided a means for checking discharge characteristics of the spillway.

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* All elevations (el) cited herein are in feet referred to mean sea level.

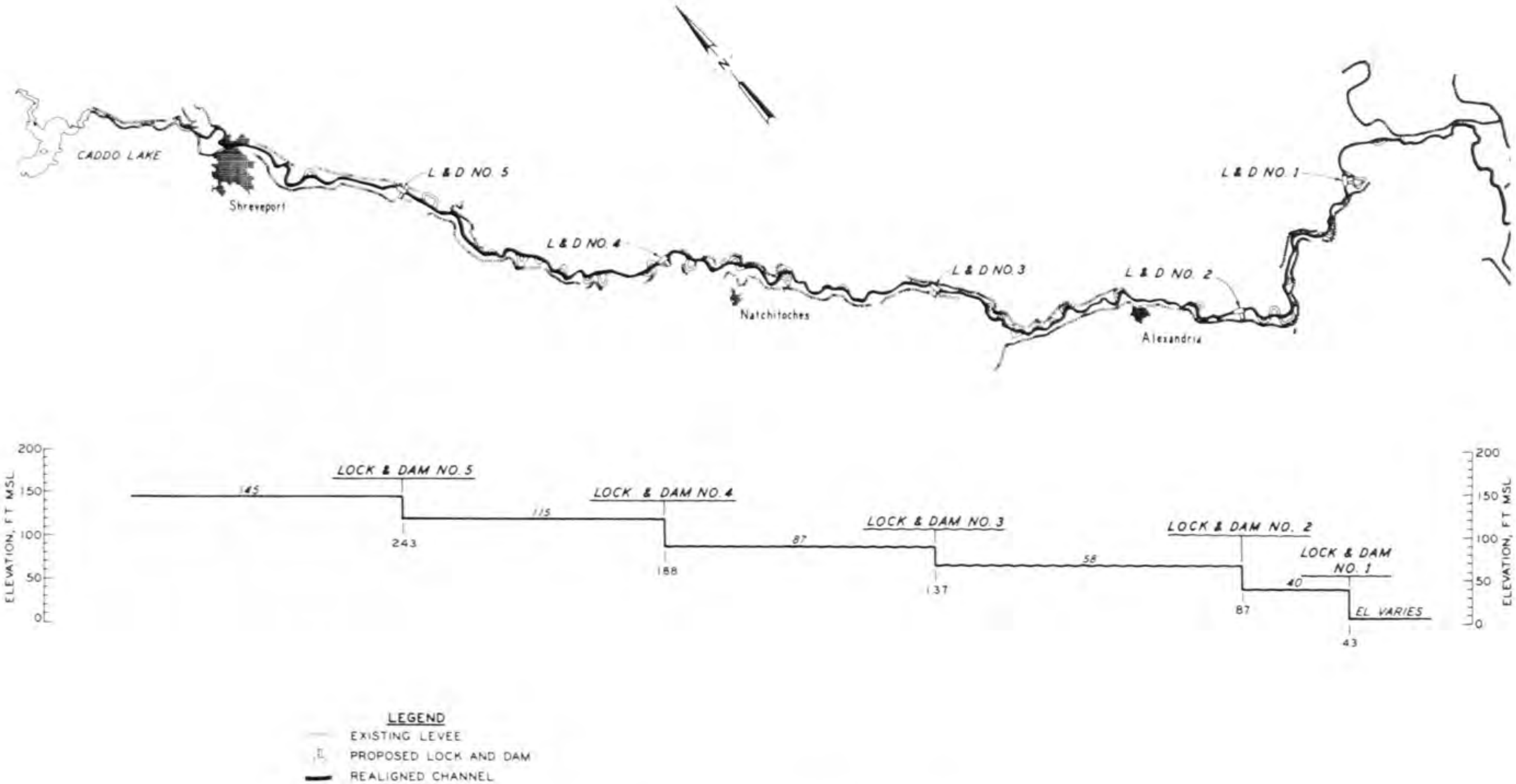

Figure 2. Location map

PART II: THE MODEL

Description

5. The investigation was conducted in a 1:36-scale model which reproduced the entire gated spillway and portions of the adjacent abutment walls on one side of the spillway as shown in Figure 3. A 600-ft

Figure 3. General view of model

length of upstream and a 1400-ft length of downstream topography were reproduced. The approach area was molded in cement mortar to sheet metal templates. The spillway weir, tainter gates, and gate piers were fabricated of sheet metal. The stilling basin and its elements were of wood which was treated with a waterproofing compound to prevent expansion. Initially, the downstream area was molded in sand covered with grout, but this area was replaced with a blanket of crushed limestone to permit study and development of the plan of riprap protection required.

Appurtenances

6. Discharges were measured with venturi meters, and water-surface elevations were measured with point gages. Sand and riprap

scour depths were measured with point gages, and velocities were measured with a pitot tube. Steel rails set to grade along the sides of the flume provided a reference plane for measuring devices. Tailwater elevations were regulated by a flap gate at the downstream end of the flume.

Scale Relations

7. The accepted equations of hydraulic similitude, based on Froudian criteria, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. General relations for the transfer of model data to prototype equivalents are as follows:

Characteristic	Dimension*	Scale Relation Model:Prototype
Length	L	$L_r = 1:36$
Area	L^2	$A_r = L_r^2 = 1:1,296$
Velocity	LT^{-1}	$V_r = L_r^{1/2} = 1:6$
Discharge	L^3T^{-1}	$Q_r = L_r^{5/2} = 1:7,776$
Force or weight	MLT^{-2}	$F_r = L_r^3 = 1:46,656$

* Dimensions are in terms of length, time, and mass.

8. Model measurements of discharge, water-surface elevation, and velocities can be transferred quantitatively to prototype equivalents by means of these scale relations. Also, the experimental data available indicate that the prototype-to-model scale ratio is valid for scaling riprap in the sizes used in this investigation. Evidences of sand scour, however, are considered only qualitatively reliable, since it is not possible to reproduce quantitatively in a model the same ratio of flow depth to the diameter of bed material representative of the prototype.

PART III: TESTS AND RESULTS

Approach Conditions

9. Approach conditions resulting with several spillway crest elevations and approach channel bottom elevations were investigated with both controlled and uncontrolled flows. The original spillway crest elevation of +4.0 and approach channel bottom elevation of -1.0 produced adequate flow conditions; however, detailed tests were waived to expedite tests with higher spillway crest elevations of +8.0 and +11.0. Tests were conducted with spillway crest elevations of 4.0, 8.0, and 11.0, so that the U. S. Army Engineer District, New Orleans, could make an economic study to determine the optimum crest elevation and number of gate bays. An approach elevation of +8.0 and a spillway with a crest elevation of +11.0 and eleven 50-ft-wide bays were selected for the prototype design.

10. Tests were conducted to compare the relative performance of the 5-ft-radius abutment with that of a 20-ft-radius abutment during both free uncontrolled and gated flow conditions. The free uncontrolled flow conditions were the most severe relative to drawdown and flow contraction and were therefore used for comparison.

11. Flow conditions and the water-surface profile along the left abutment (5-ft-radius) are shown in Photo 1a and Plate 2, respectively. Flow did not separate from the abutment during free uncontrolled flow conditions and performance with gated operations was most tranquil and satisfactory.

12. Similar results observed with the 20-ft-radius abutment are shown in Photo 1b and Plate 3. Obviously, the contraction of flow was not as great as that observed with the 5-ft radius abutment.

13. It is considered that the abutment of 5-ft radius is satisfactory from the hydraulic performance standpoint and that an increased radius is not warranted unless it is beneficial to structural or other interests.

Spillway Calibration

14. Tests were conducted to determine the effect of the approach channel elevation on discharge capacity of the spillway. Tests were conducted with the upstream channel bottom at elevations of 6.0, 8.0, and 11.0 with the spillway crest or gate sill at el 11.0. Plate 4 is a plot of discharge versus head on the spillway crest (difference between the upper pool and spillway crest) for free uncontrolled flow. These data were obtained with only one gate open since the limited discharge capacity of the model facility would not permit operation with all of the gates fully open. Plate 4 indicates that the structure is only slightly more efficient with approach depths of 3 and 5 ft.

15. Plots of head on the spillway crest versus discharge for both controlled and uncontrolled free flows are provided in Plate 5. These data were obtained with as many gates operating as the model discharge capacity would allow, and the total discharge was divided by the number of gates opened to obtain the discharge per gate bay.

16. Comparison of discharge coefficients computed from the limited data obtained from the Red River Spillway model with those contained in WES TR No. 2-655* (Arkansas River Spillways) indicates very close agreement. Plate 6 is a plot of free uncontrolled flow discharge coefficients taken from the Arkansas River Spillway report along with the coefficients computed from the limited Red River Spillway data. The effective length of crest used in computing these coefficients was determined by using two abutment contractions since the data were obtained with only one gate operating. It is suggested that the coefficients shown in the Arkansas River Spillway report be used to determine discharge coefficients for the Red River Spillways. Plate 7 is a plot of discharge coefficients for submerged controlled flow obtained from both the Red River and the Arkansas River models.

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* J. L. Grace, "Spillway for Typical Low-Head Navigation Dam, Arkansas River, Arkansas; Hydraulic Model Investigation," Technical Report No. 2-655, Sep 1964.

Stilling Basin Development

17. As stated previously, tests were conducted to develop satisfactory stilling basin designs for single-gate operation with spillway crest elevations of 4.0, 8.0, and 11.0, so that the New Orleans District could make an economic study to determine the optimum crest elevation and number of gate bays for the subject spillway. The designs were developed from consideration of velocities in the exit channel and observations of flow conditions with a tailwater elevation of 10.0. Velocities in the exit channel also were obtained with tailwater elevations of 4.0 and 16.0 and with each of the spillway and stilling basin designs.

Original design crest el +4.0

18. The original design stilling basin (Plate 1) had an 80-ft-long horizontal apron at el -14.2 and a 3.2-ft-high vertical end sill. Tests of the original design indicated the need for a lower and longer basin to dissipate the energy of flows from a single gate bay with the gate fully open and the minimum tailwater (el 4.0). A hydraulic jump did not form in the basin and the flow swept downstream with velocities of 40 to 50 fps (Photo 2a). The measured depth of flow entering the basin with a single gate fully open was 11.5 ft. Both single and double rows of 10-ft-high baffle blocks improved flow conditions; however, spray action occurred with the minimum tailwater (el 4.0). A tailwater of el 10.0 or higher, which will be available at least 98 percent of the time, improved energy dissipation as shown in Photo 2b; however, the exit velocities remained excessively large due to the additional return flow entrained with that released through a single gate bay.

Alternate designs crest el +4.0

19. Since the original design stilling basin with and without two rows of 10-ft-high baffle blocks did not perform satisfactorily for single-gate operations, several alternate designs were tested in an effort to obtain good energy dissipation. The basin was first lowered to el -20 and lengthened to 100 ft with a 1V on 5H upslope provided to the exit channel bottom in an effort to establish a satisfactory basin design for single-gate operation with a tailwater elevation of 10.0.

Numerous sizes and arrangements of baffles were tested without much improvement until pier extensions 45 ft long and 35 ft high were installed to eliminate the return flow (Photo 2) that occurred with only one bay operating. The best basin tested with a spillway crest of el 4.0 was type 6 (Plate 8). Maximum velocities 2 ft above the exit channel and 10 ft downstream from the end sill were 18 fps with a normal pool elevation of 40.0 and a tailwater elevation of 10.0. With the tailwater lowered to el 4.0, the maximum velocities increased to 28 fps. The maximum velocities 500 ft downstream from the basin were 15.9 and 20.1 fps, respectively, for tailwater elevations of 10.0 and 4.0. These velocities were higher than those desired and led to the decision to raise the spillway crest 4 ft to el 8.0.

Crest el +8.0

20. With the crest at el 8.0, the basin apron was raised to el -14.0 (the highest desirable for structural reasons). Various pier extensions and baffle arrangements were tested with one gate operating fully and then one-half open. The type 9 design shown in Plate 9 was considered the optimum design for the open, half-gated flow with a tailwater elevation of 10.0. Flow conditions with the type 9 design and tailwater elevations of 4.0, 10.0, and 16.0 are shown in Photo 3. A tailwater elevation of 14.0 was required to maintain a good hydraulic jump in this basin with one gate fully open (Figure 4). A forced jump was maintained in the basin with one gate fully open and a tailwater elevation of 10.0.

21. Tests with four gates at equal openings indicated the pier extensions in the type 9 design could be eliminated if single-gate operation was never required. Flow conditions observed with four center bays operating at 10-ft openings with tailwater elevations of 4.0, 10.0, and 16.0 and the type 9 basin without pier extensions are shown in Photo 4.

Crest el 11.0 (recommended)

22. Tests were conducted to develop stilling basins that would provide adequate performance for each of the following conditions with a spillway crest elevation of 11.0.

a. Normal upper pool elevation of 40.0, minimum tailwater

Figure 4. Flow conditions 50 ft downstream of stilling basin at el -9.0 with type 9 basin, one gate fully open, crest elevation of 8.0, pool elevation of 40.0, tailwater elevation of 14.0, discharge of 22,600 cfs, and maximum velocity of 14.8 fps

elevation of 4.0, and one gate approximately one-half open to permit passage of debris.

b. Conditions the same as those in subparagraph a, except with a tailwater elevation of 10.0, which is expected 98 percent of the time.

c. Normal upper pool and minimum tailwater with one gate fully open; this condition should occur only during an emergency or misoperation of the gate.

d. Conditions the same as those in subparagraph c, except with a tailwater elevation of 10.0, which is expected 98 percent of the time.

The sequence of model testing was to establish the best stilling basin designs and then determine the riprap requirements for adequate downstream protection.

23. With a spillway crest elevation of 11.0, three stilling basin designs were developed relative to the above-listed design conditions that could be adopted for the subject project. Each basin was designed to provide adequate energy dissipation for single-gated flows and prevent maximum bottom velocities from exceeding 15 fps downstream of the basin.

Details and permissible operating conditions for each design are shown in Plates 10-12 (types 7, 16, and 17 basins, respectively).

24. A spillway crest elevation of 11.0 was selected for the prototype structure, and the type 17 stilling basin design with the apron at el -14.0 was recommended for a single gate one-half open and a tailwater elevation of 10.0 (Plate 12). According to the New Orleans District engineers, no monetary benefit could be derived from raising the basin higher than el -14.0.

25. Two stilling basins with lower apron elevations were developed to accommodate the other three design conditions. The type 7 stilling basin (Plate 10) with an apron elevation of -20.0 was recommended for the two design conditions of a single gate one-half open with a tailwater elevation of +4.0 and a single gate fully open with a tailwater elevation of +10.0. An apron elevation of -28.0 (type 16 stilling basin shown in Plate 11) was required to accommodate a single gate fully open with a tailwater elevation of +4.0.

26. Maximum velocities used in determining riprap sizes for the various designs and flow conditions are listed in Table 1. All velocities were taken 2 ft above the channel bottom at el -9.0 for a single gate one-half and fully open. Table 1 indicates the advantages of the higher spillway crest in reducing the velocities and the downstream riprap requirements. The selection of 11 bays and a crest elevation of 11.0 reduced the unit discharge through the structure and the maximum velocities in the exit channel.

Upstream and Downstream Riprap Protection

27. Tests were conducted to determine the minimum size and extent of riprap required both upstream and downstream of the spillway with a crest elevation of 11.0. These tests were conducted with a normal upper pool elevation of 40.0 and tailwater elevations of 4.0 and 10.0. In Table 2 the gradations of riprap simulated and tested in the model are compared with those based on Engineer Technical Letter (ETL) 1110-2-120 (Incl 1, page 3 of 7) for riprap placed in the dry. The procedure used to determine the minimum size of protection required for a

certain flow condition was to reduce the size of riprap and test until failure occurred, and the next larger stone that had been stable in the model was considered to be the minimum size of protection required.

Upstream protection

28. Tests with the approach channel at el 8.0 indicated that 18-in. riprap (blanket thickness) would be required in the area immediately upstream from the spillway with one gate one-half open and minimum tailwater. Velocities measured 2 ft above the channel bottom in this area are shown in Plate 13. When the approach area was lowered to el 6.0, 15-in. riprap was adequate with the same flow conditions.

29. Velocities measured 2 ft above el 8.0 and the invert of the approach area that resulted with a 5-ft-radius abutment, a 24-in.-thick blanket of riprap that extended 60 ft upstream from the face of the dam, one gate fully open, a pool elevation of 40.0, and a tailwater elevation of 16.0 are presented in Plate 14. The only riprap movement observed during an extended period of operation occurred near the pier nose where a maximum velocity of 20.4 fps was measured as shown in Plate 14. Due to the flow acceleration and drawdown induced at the pier nose and abutment, an additional blanket thickness should be provided for a length of about 20 ft in these areas. The 24-in. riprap blanket was stable with the same gate one-half open, a pool elevation of 40.0, and a tailwater elevation of 10.0. Earlier tests indicated an 18-in. riprap blanket was also stable at el 8.0 with one gate one-half open, and a minimum 15-in. riprap blanket wes recommended with an approach elevation of 6.0.

Downstream protection

30. Tests to determine the protection needed downstream from the structure were conducted with the three stilling basin designs developed earlier in the testing program relative to the four possible design conditions that may be adopted for the subject project. All three designs were installed in the model simultaneously (Photo 5) but were tested separately for the various flow conditions.

31. The type 17 stilling basin with the apron at el -14.0 was designed for operation with one gate one-half open and a tailwater elevation of 10.0. This basin and the downstream riprap are shown in Photo 6.

Photo 7 shows flow conditions with the basin operating under the design conditions. The recommended riprap protection for use downstream of the type 17 stilling basin is shown in Plate 15. Lowering the tailwater to el 4.0 with this basin caused spray off the baffle blocks as shown in Photo 8, thereby causing failure of the riprap. Thus, it should be emphasized that this basin with the recommended riprap is not adequate for operation under minimum tailwater conditions. Likewise, extents and gradations of riprap less than that recommended (Plate 15) will permit failure with the design flow (Photo 9).

32. The type 7 stilling basin with the apron at el -20.0 was designed for operation with one gate fully open and a tailwater elevation of 10.0 or with one gate one-half open and a tailwater elevation of 4.0. The recommended riprap protection for both of these conditions was identical and is shown in Plate 16. Tests conducted with the type 7 basin operating with one gate one-half open and a tailwater elevation of 10.0 determined how much the riprap size could be reduced. The minimum protection for this condition is shown in Plate 17.

33. The type 16 stilling basin with the apron at el -28.0 was designed for operation with one gate fully open and a tailwater elevation of 4.0. The recommended riprap protection for this condition is shown in Plate 18. Tests were conducted with the type 16 basin operating with one gate one-half open and a tailwater elevation of 10.0 to determine how much the riprap size could be reduced. The minimum protection for this condition is shown in Plate 19.

34. The best protection for the downstream end of the riprap blankets was a preformed scour hole with 1V on 5H downslope from el -11.0 to el -19.0 as shown on all riprap plans. Some stones move off the downstream toe during extended operation and expose the filter cloth. These relocated stones tend to protect against undercutting of the riprap protection as the scour continues below el -19.0 on an approximate 1V on 5H downslope. An extra layer of riprap should be placed on the downstream 20 ft of the blanket to reduce filter exposure and provide sufficient protection against undermining the riprap blanket. The upslope of the preformed scour hole to el -7.0 shown as 1V on 5H could be made as

steep as 1V on 2H if economically advantageous.

35. Excellent performance was observed with the types 17, 7, and 16 stilling basins under normal operation (equal gate openings) with or without pier extensions. Flow conditions in the three basins with the gates open 10 ft and a tailwater elevation of 10.0 are shown in Photo 10.

36. Various flow conditions observed with all gates operating and the type 17 stilling basin without pier extensions are shown in Photos 11 and 12 and indicate good energy dissipation with normal operations. Photo 11 shows conditions for all gates open 2 ft with tailwater elevations of 10.0, 15.0, and 25.0. Photo 12 shows conditions for all gates open 4 and 6 ft with a tailwater elevation of 10.0.

37. Velocities measured 2 ft above the downstream riprap protection, both with and without 45-ft-long pier extensions, are provided in Plates 20 and 21, respectively. All velocities were measured with a single gate one-half open, a pool elevation of 40.0, and a tailwater elevation of 10.0. Higher velocities occurring without the pier extensions necessitate a 36-in.-thick riprap blanket for minimum protection with one gate one-half open. Figure 5 shows the results of tests of lighter (24- and 18-in.) riprap protection. A 30-in.-thick blanket was sufficient with the pier extensions in place, and either plan of protection should include the 50-ft-wide heavy riprap blanket along both the vertical lock wall and the sloping bank. A 24-in.-thick riprap blanket provided adequate protection of the 1V on 4H bank slope beginning 50 ft downstream from the stilling basin end sill.

Sand scour patterns

38. Downstream sand scour patterns obtained with the type 17 stilling basin without pier extensions are shown in Figure 6. The scour patterns and slight movement of both 24- and 18-in. riprap observed after 6-hr (prototype) operation without a preformed scour hole at the downstream end of the blanket emphasize the need for sloping the riprap downward at the termination of the blanket.

39. The 30-in. riprap adjacent to the stilling basin and the 24-in. riprap downstream as shown in Plate 15 remained stable after extended operations and are recommended for use with the type 17 stilling

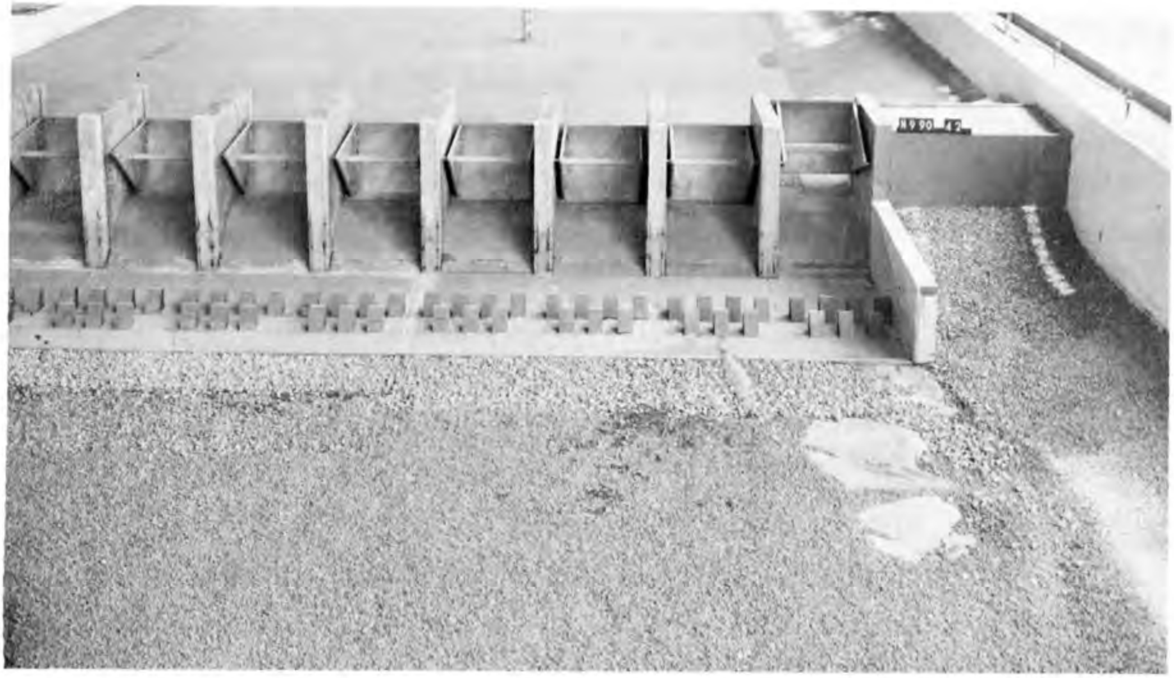

Figure 5. Type 17 stilling basin (without pier extensions) with one gate half open, pool elevation of 40.0, tailwater elevation of 10.0. Note failure of 24- and 18-in.-thick riprap blanket after 15-hr (prototype) operation

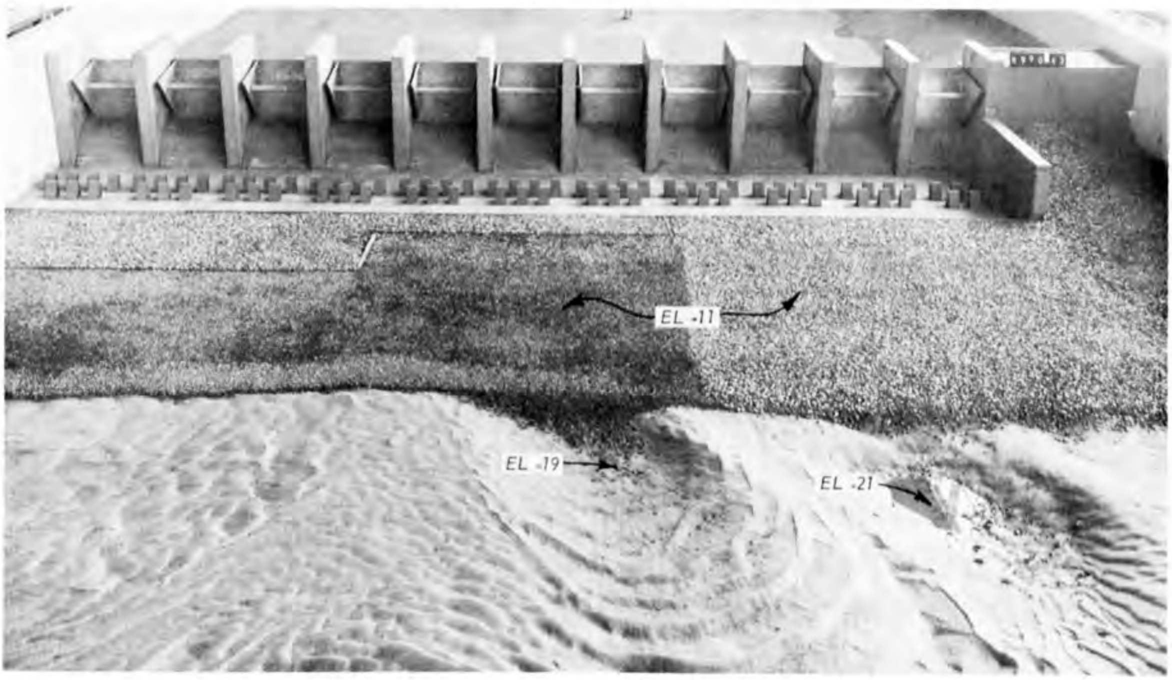

Figure 6. Type 17 stilling basin (without pier extensions) with one gate one-half open, with apron elevation of -14.0, pool elevation of 40.0, and tailwater elevation of 10.0. Note pattern of scour downstream of 18-in. riprap blanket (left) and 24-in. riprap blanket (right) after operating 6 hr (gate 6) and 12 hr (gate 3)

basin when designing for the tailwater expected 98 percent of the time.

Downstream training walls

40. Tests were conducted with various downstream training walls to determine the minimum length and height of this wall that will result in satisfactory flow conditions. These tests were conducted with both normal and single-gate operation. The minimum proposed length of this wall is 106 ft with the top at el 25.0. Single-gate flows with the proposed training wall and fully and one-half open gates are shown in Photo 13, and multigate flows are shown in Photo 14.

Loose Barge Tests

41. Several emergency conditions were simulated with a model barge (35 ft wide and 140 ft long) that was permitted to drift into the structure and through any of the fully open gates. These tests were conducted primarily to determine if a loose barge loaded to a 9-ft draft could be flushed through the stilling basin. Loaded barges tended to hang on the first row of baffle piers even with 1-on-1 deflector vanes attached to their upstream face when the depth of water over the top of the baffles was less than 25-30 ft due to the relatively large drawdown or slope of the water surface through the structure. For example, a basin with an apron elevation of -28.0 and 10-ft-high baffles would pass a loose barge when the tailwater elevation was equal to or greater than 10.0 and the gate was fully open. A rather deep basin appears to be required for passing loose barges. The upper pool could be lost with a barge trapped on the first row of baffle piers for an extended period of time since the respective gate could not be closed. Crest piers of sufficient length to permit installation of stop logs or bulkheads both upstream and downstream of a barge appear to be required for isolation and ready salvage of a barge trapped on the baffle piers. However, it is desired that the downstream end of the crest piers be located upstream of the first row of baffle piers in stilling basins designed for emergency operations with one gate fully open. One solution, if accidents are deemed "common occurrence," would be to provide a deep basin capable of passing loose barges.

PART IV: DISCUSSION OF RESULTS

42. Satisfactory flow conditions were observed for normal gate flows with the approach area either 3 or 5 ft below the crest (el 6.0 or 8.0). The advantage of lowering the approach to el 6.0 would be to reduce the size of the upstream riprap protection.

43. Tests to determine the discharge characteristics revealed that the data obtained in a previous investigation* can be used to determine the coefficients of discharge for the Red River No. 1 Spillway.

44. Tests of the original design spillway with a crest elevation of +4.0 revealed the need for a lower and longer basin to dissipate flows through a single-gate one-half or fully open for the normal pool and the minimum tailwater. Stilling basin tests demonstrated that the apron should be lowered 6 ft to el -20.0 and lengthened 20 ft to provide a total length of 100 ft with a 1V on 5H upslope to the exit channel (el -11.0) in order to establish a satisfactory basin design for full single-gate operation with an el 10.0 tailwater. The addition of two rows of 10-ft-high by 7-ft-wide baffle blocks and pier extensions 45 ft long and 35 ft high was essential to obtain desirable stilling basin action with a tailwater elevation of 4.0.

45. Tests were conducted with the spillway crest raised to el 8.0 to develop a more economical stilling basin for a 16-ft single-gate opening (one-half) with an el 10.0 tailwater. With the spillway crest at el 8.0, the basin apron was raised to el -14.0 (highest desirable for structural reasons). The optimum basin for half-gate flow with the el 8.0 spillway crest consisted of a 100-ft-long horizontal apron with two rows of 10-ft-high by 7-ft-wide baffle blocks at 50 and 67 ft from the toe of trajectory and 45-ft-long by 29-ft-high pier extensions to eliminate return flows and eddies within the basin.

46. Stilling basin tests were also conducted with a spillway crest at el 11.0. The sponsor determined that no monetary benefit could be derived from raising the basin higher than el -14.0. Therefore, the

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* Grace, op. cit.

basin developed with the spillway crest at el 8.0 was considered optimum for a spillway crest at el 11.0. However, the maximum velocities were reduced approximately 4 fps in the exit channel because of the reduced unit discharge with the higher crest, thereby lowering the cost of the downstream riprap protection.

47. Three stilling basin designs were developed for a spillway with a crest elevation of 11.0 and the four possible design conditions described in paragraph 22. Each basin was designed to provide adequate energy dissipation for single-gate flows and prevent maximum bottom velocities from exceeding 15 fps downstream of the basin. Performance was excellent with multigate normal operations.

48. Satisfactory riprap protection plans were developed for the upstream and downstream approaches and the three stilling basin designs. The gradations of riprap simulated and tested in the model compare with those based on ETL 1110-2-120 for 165 pcf of riprap placed in the dry with a 1.0 D_{100} max thickness. The riprap gradations and thicknesses specified in Plate 15 were the minimum required for stability in the model, and the riprap should be placed thicker (1.50 D_{100} max) in the prototype to fully comply with paragraph 3b(3) of ETL 1110-2-120 since the riprap will be subjected to turbulent flow, even though it will be placed in the dry.

49. Efforts to establish additional design guidance for riprap protection based on the results of these tests were made and will be incorporated in the final report on Red River Spillway No. 2.

Table 1

Maximum Velocities Used in Determining Riprap Sizes

Stilling Basin Types	Elevations, ft			Maximum Velocity at El -9.0, fps Distance of Basin, ft			
	Crest	TW	Basin	50	150	300	500
			One Gate Fully Open				
1	+4	+4	-13.1	45	--	--	--
7	+4	+4	-20	28	27.7	25.5	20.1
	+4	+10	-20	18	17.8	16.0	15.9
9	+8	+4	-14	26.8	26.0	25.2	21.3
	+8	+10	-14	17.4	17.4	17.0	15.3
	+8	+16	-14	15.0	14.4	13.4	13.2
9	+11	+10	-14	14.4	14.0	13.6	11.8
			One Gate One-Half Open				
7	+4	+4	-20	24.5	24.0	22.4	18.3
	+4	+10	-20	15.5	14.8	14.1	13.2
9	+8	+4	-14	16.6	15.9	14.8	13.8
	+8	+10	-14	12.2	10.8	11.4	10.8
	+8	+16	-14	9.6	10.2	9.6	9.4
9	+11	+4	-14	11.4	11.0	10.5	10.0
	+11	+10	-14	7.8	7.4	7.2	6.7
	+11	+16	-14	5.5	6.2	5.0	4.8

Note: Normal upper pool elevation 40.0.
TW designates tailwater.

Table 2

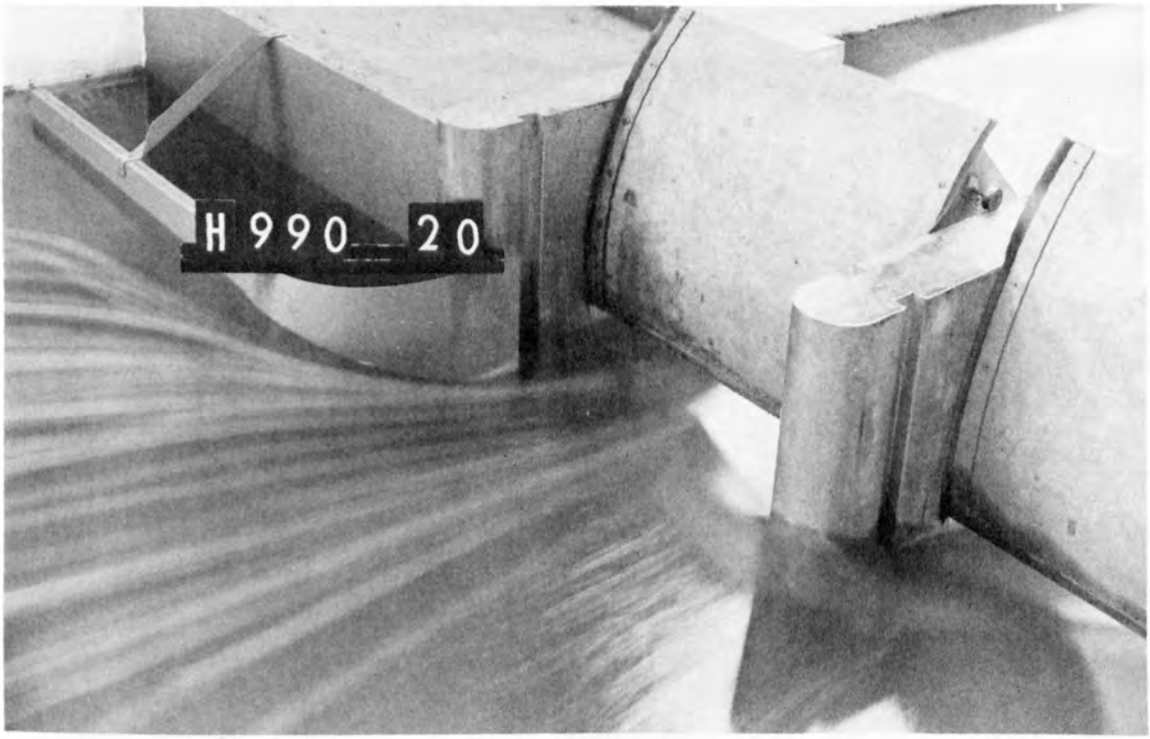
Riprap Gradations

Blanket Thickness* in.	Percent Lighter by Weight	Recommended Limits of Stone by Weight, lb**	Test Weight lb
15	100	169 - 67	116
	50	50 - 34	42
	15	25 - 11	23
18	100	292 - 117	116
	50	86 - 58	65
	15	43 - 18	30
24	100	691 - 276	294
	50	205 - 138	116
	15	102 - 43	46
27	100	984 - 394	980
	50	292 - 197	210
	15	146 - 62	60
30	100	1350 - 540	980
	50	400 - 270	294
	15	200 - 84	116
36	100	2333 - 933	980
	50	691 - 467	448
	15	346 - 146	196

* Based on placement in the dry.

** From ETL 1110-2-120 for 165 pcf of riprap placed in the dry with a 1.0 D_{100} max thickness.

a. 5-ft radius abutment



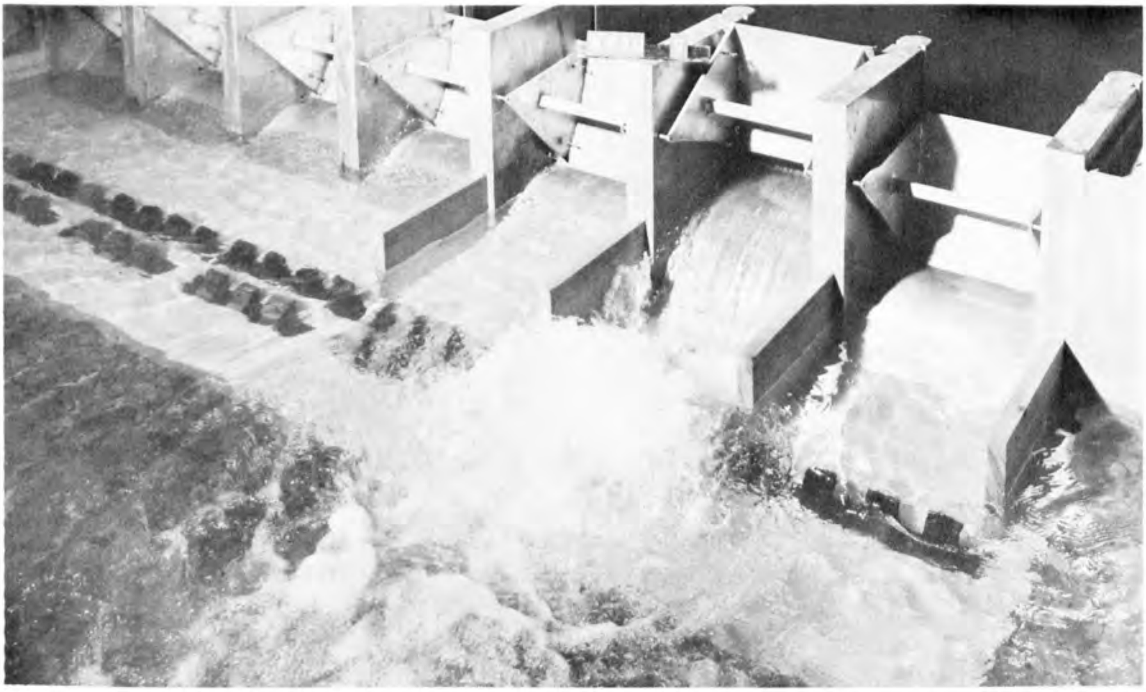
b. 20-ft radius abutment

Photo 1. Flow conditions at abutment with crest elevation of 11.0, pool elevation of 40.0, and tailwater elevation of 10.0

a. Tailwater elevation of 4.0

b. Tailwater elevation of 10.0

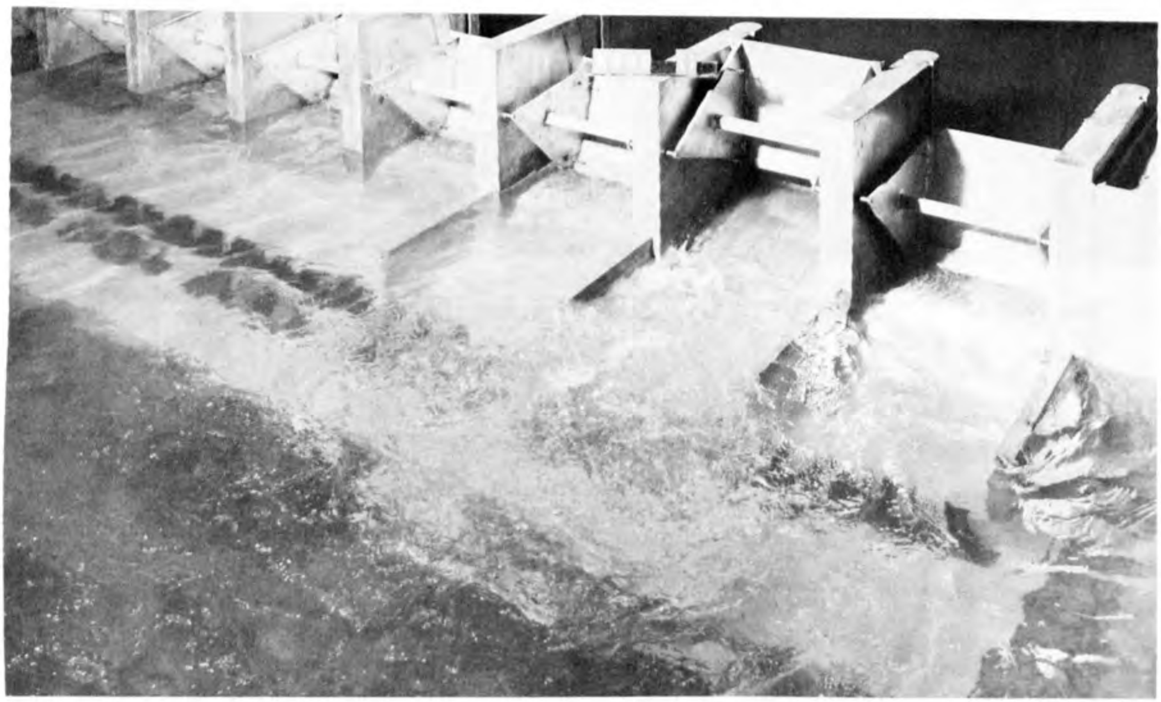
Photo 2. Flow conditions; original design stilling basin without baffles, with single gate fully open, and with pool elevation of 4.0



a. Tailwater elevation of 4.0, maximum velocity of 16.6 fps at el -9.0

b. Tailwater elevation of 10.0, maximum velocity of 12.2 fps at el -9.0

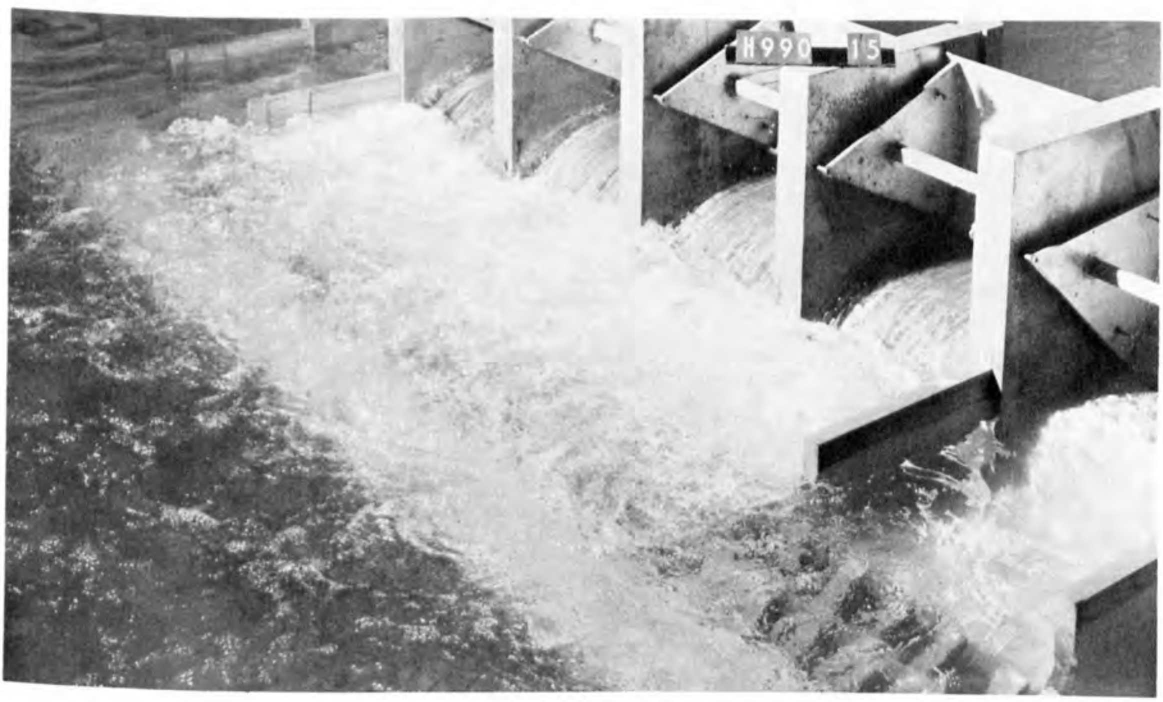
Photo 3. Flow conditions 50 ft downstream of endsill; type 9 stilling basin design, single gate open 16 ft, crest elevation of 8.0, and pool elevation of 40.0 (sheet 1 of 2)



c. Tailwater elevation of 16.0, maximum velocity of 9.6 fps at el -9.0

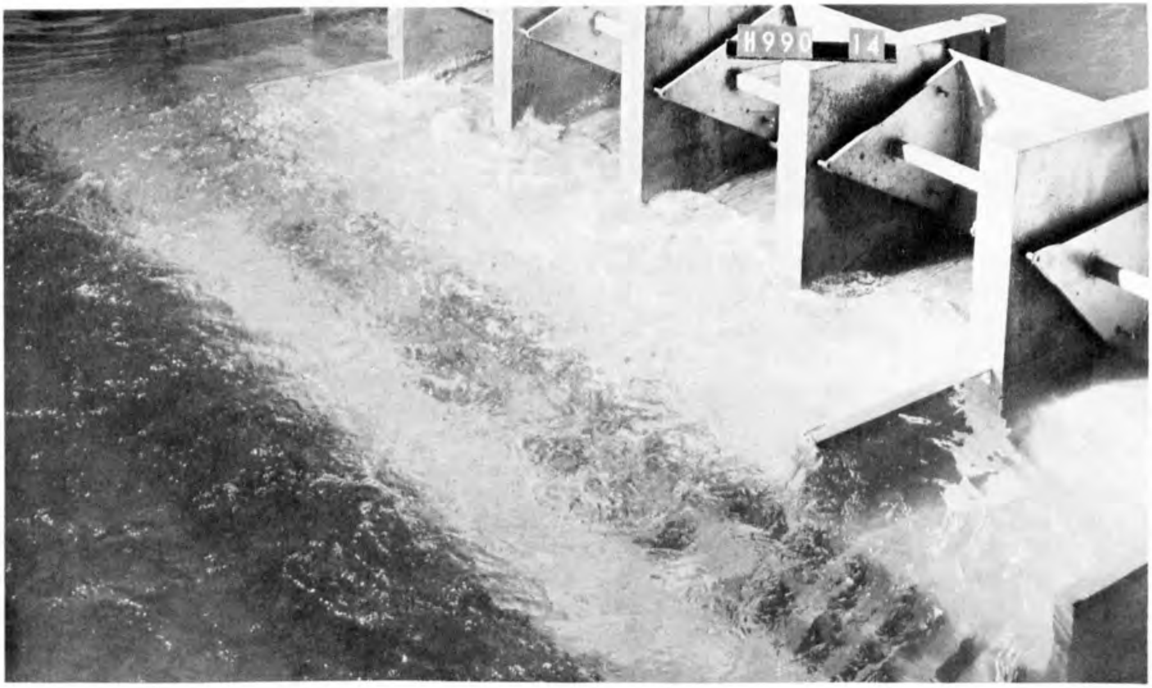
Photo 3 (sheet 2 of 2)

a. Tailwater elevation of 4.0, maximum velocity of 14.4 fps at el -9.0



b. Tailwater elevation of 10.0, maximum velocity of 9.4 fps at el -9.0

Photo 4. Flow conditions 50 ft downstream of endsill; type 9 stilling basin without pier extensions and four bays operating with 10-ft gate openings, crest elevation of 8.0, and pool elevation of 40.0
(sheet 1 of 2)



c. Tailwater elevation of 16.0, maximum velocity of 7.8 fps at el -9.0

Photo 4 (sheet 2 of 2)

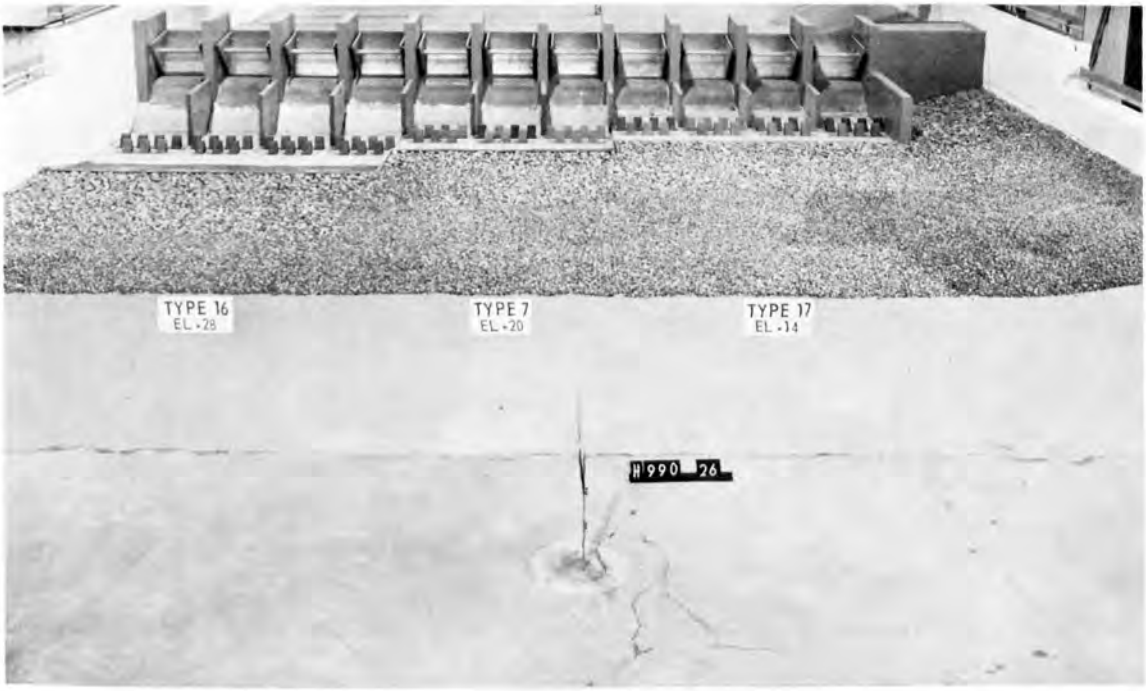


Photo 5. Dry bed of stilling basins; types 16, 7, and 17 (elevations of -28.0, -20.0, and -14.0, respectively)

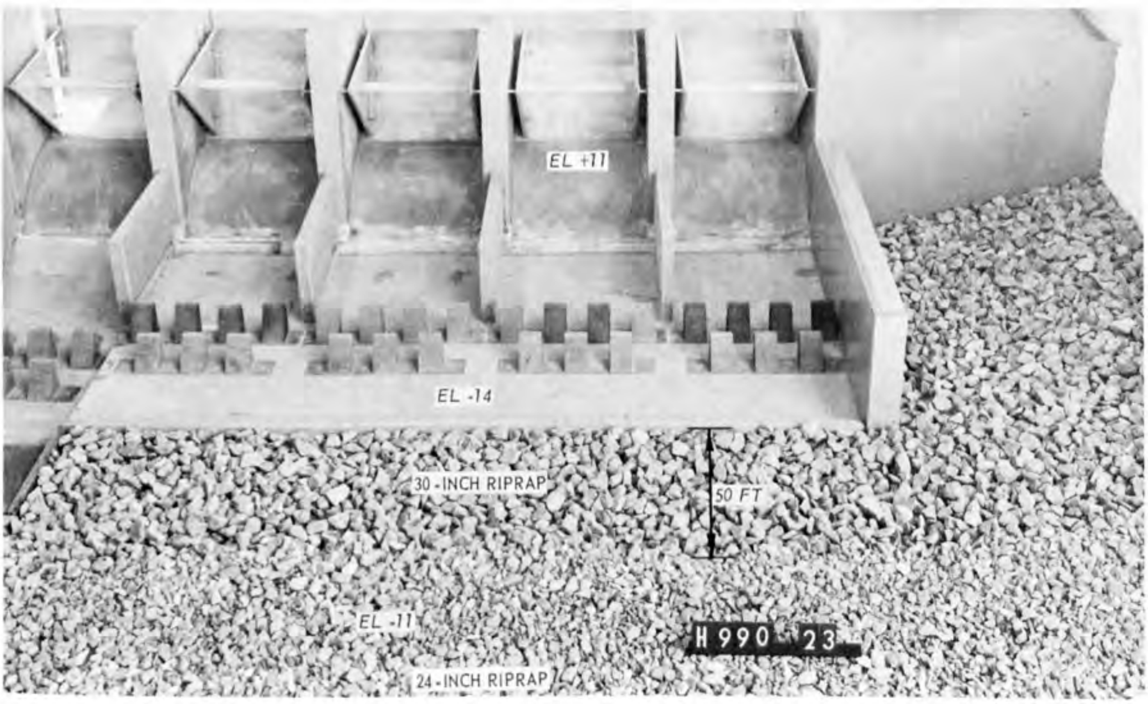


Photo 6. Type 17 stilling basin

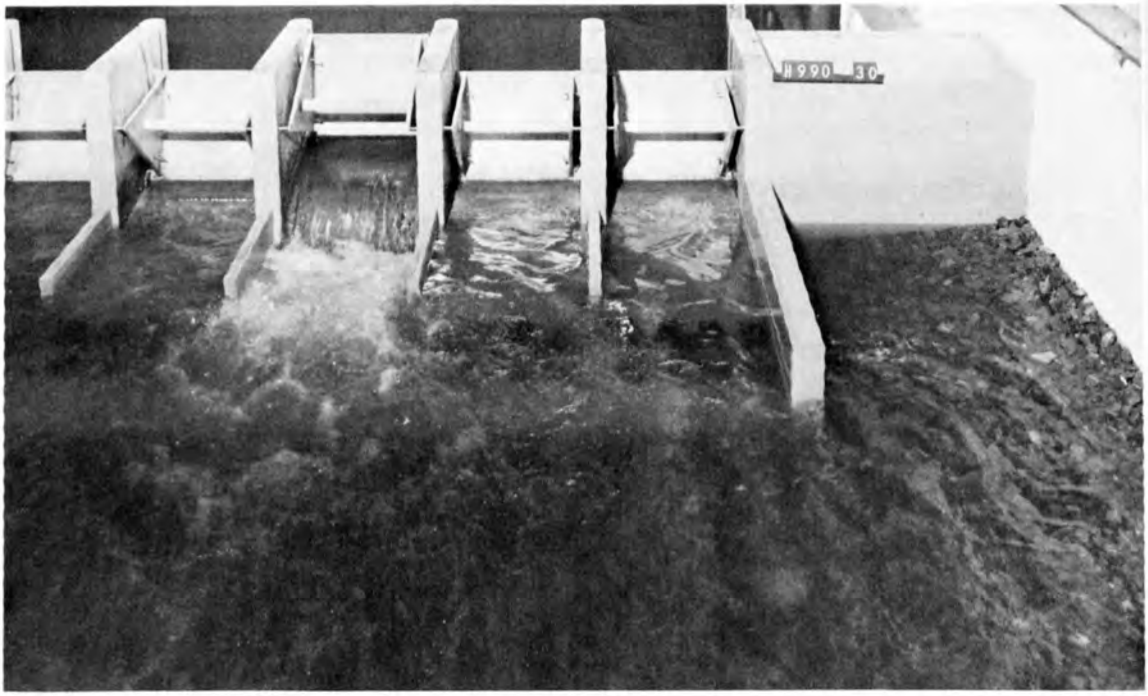


Photo 7. Flow conditions; type 17 stilling basin with 14.5-ft gate opening, pool elevation of 40.0, and tailwater elevation of 10.0. Note good hydraulic jump action

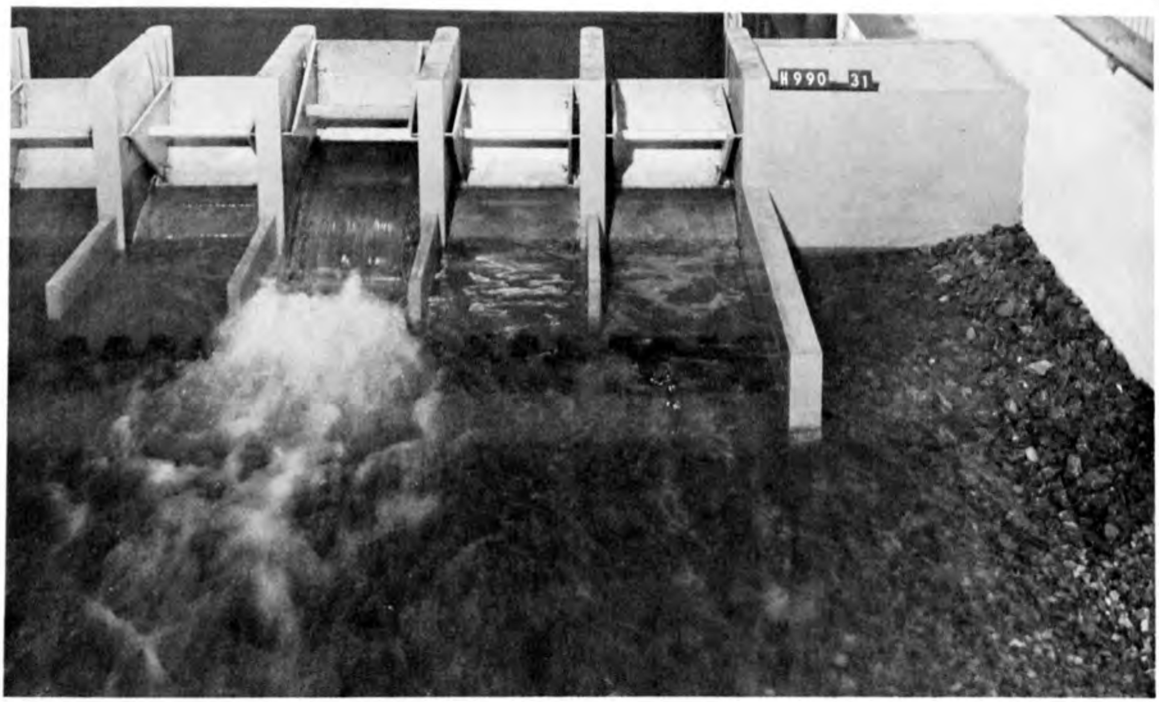
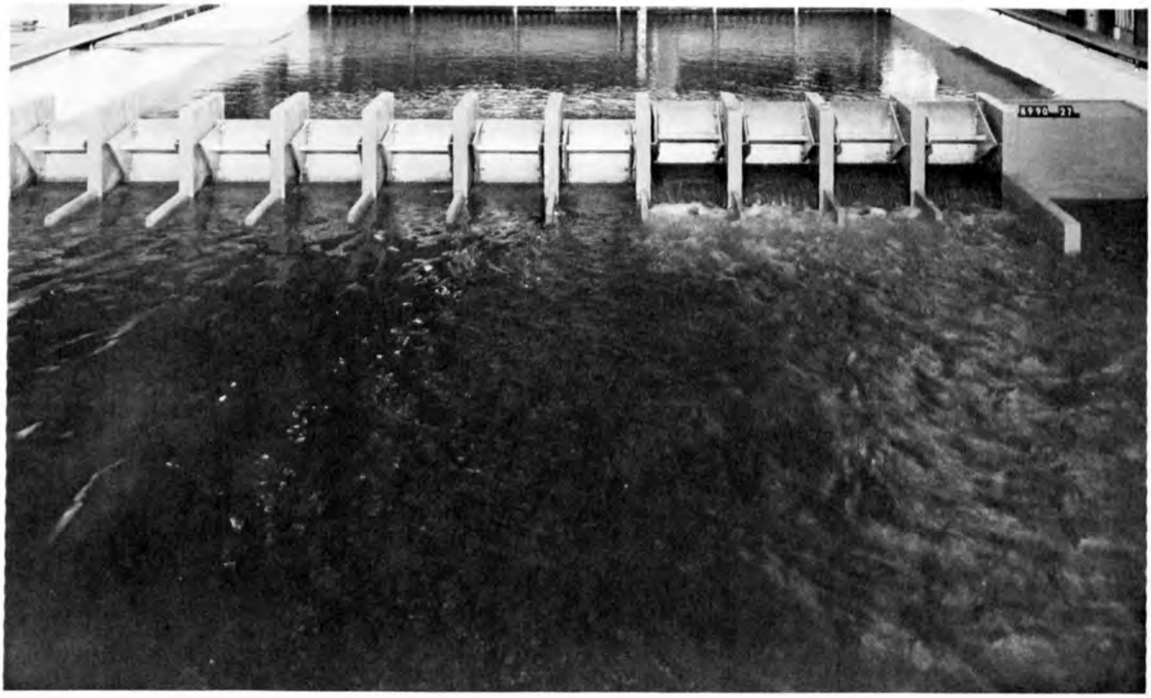
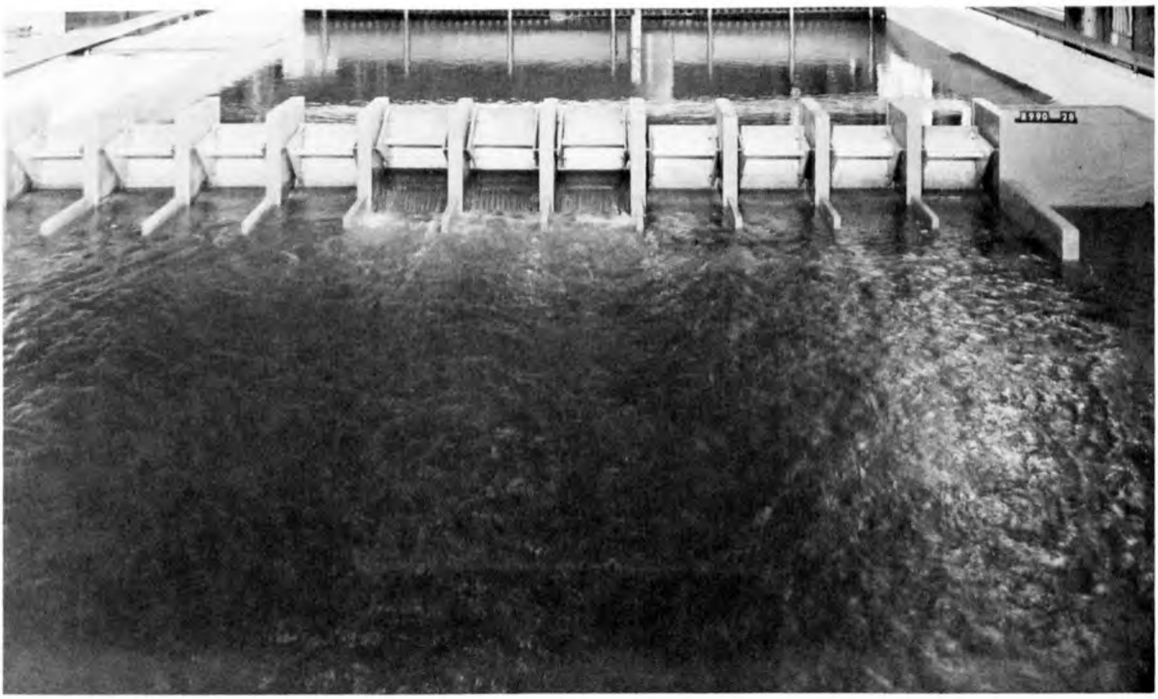


Photo 8. Flow conditions; type 11 stilling basin with 14.5-ft gate opening, pool elevation of 40.0, and tailwater elevation of 4.0. Note spray action

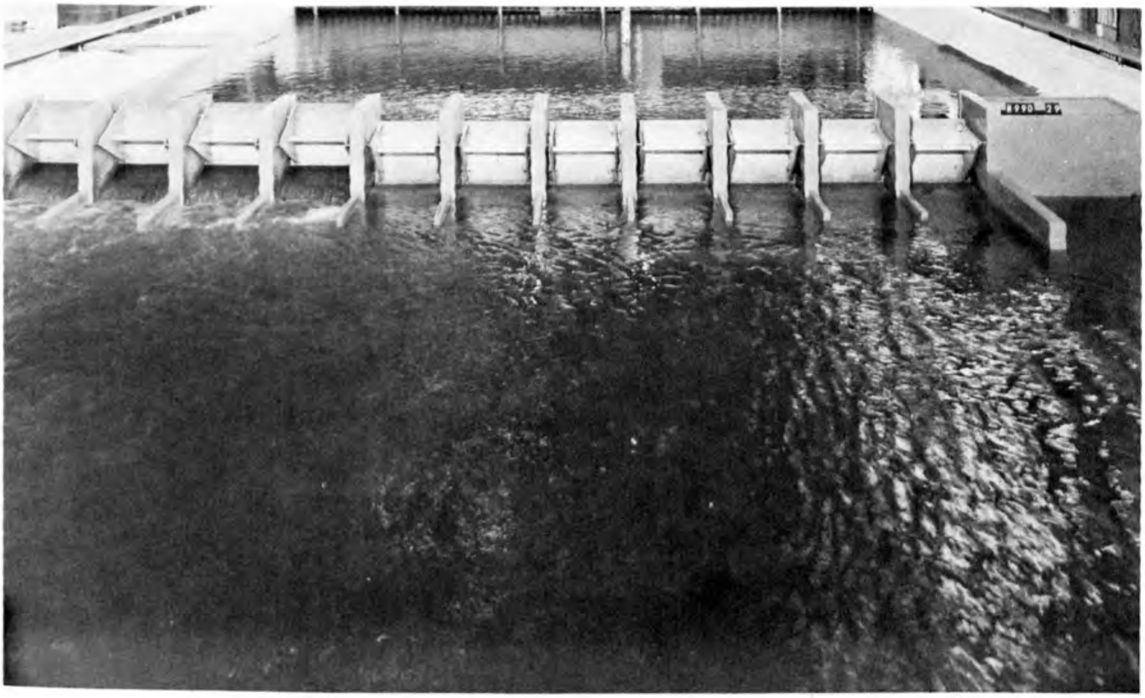


a. Type 17 basin with four gates open 10 ft



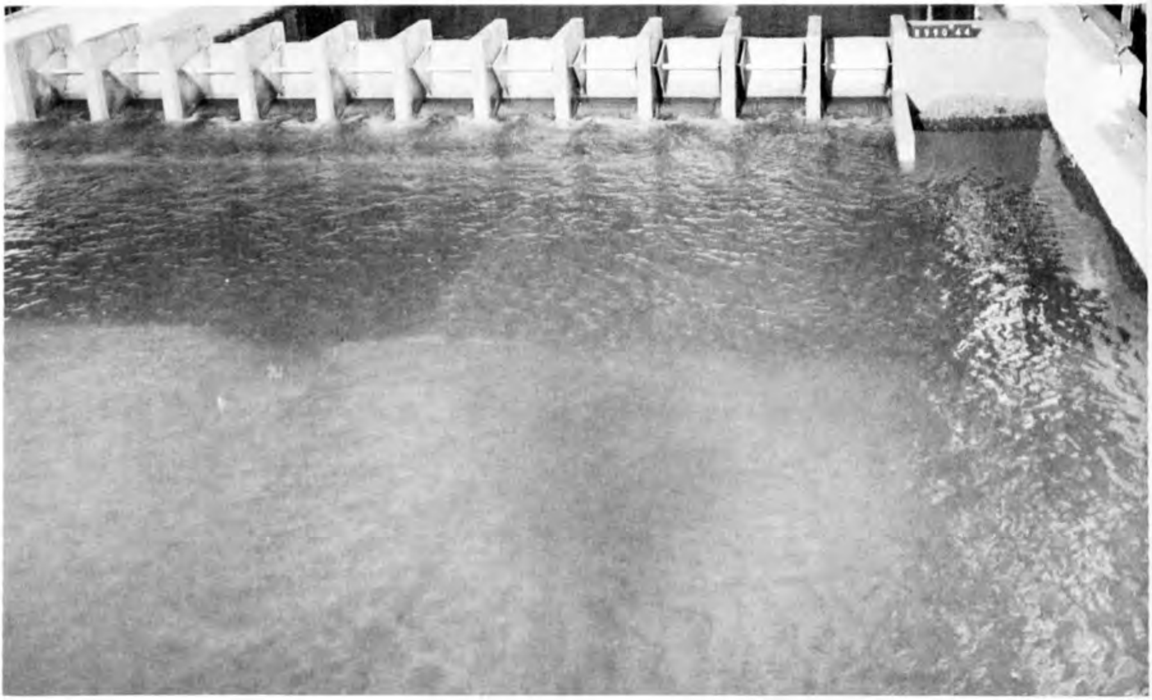
b. Type 7 basin with three gates open 10 ft

Photo 10. Flow conditions in stilling basins with pool elevations of 40.0 and tailwater elevations of 10.0 (sheet 1 of 2)

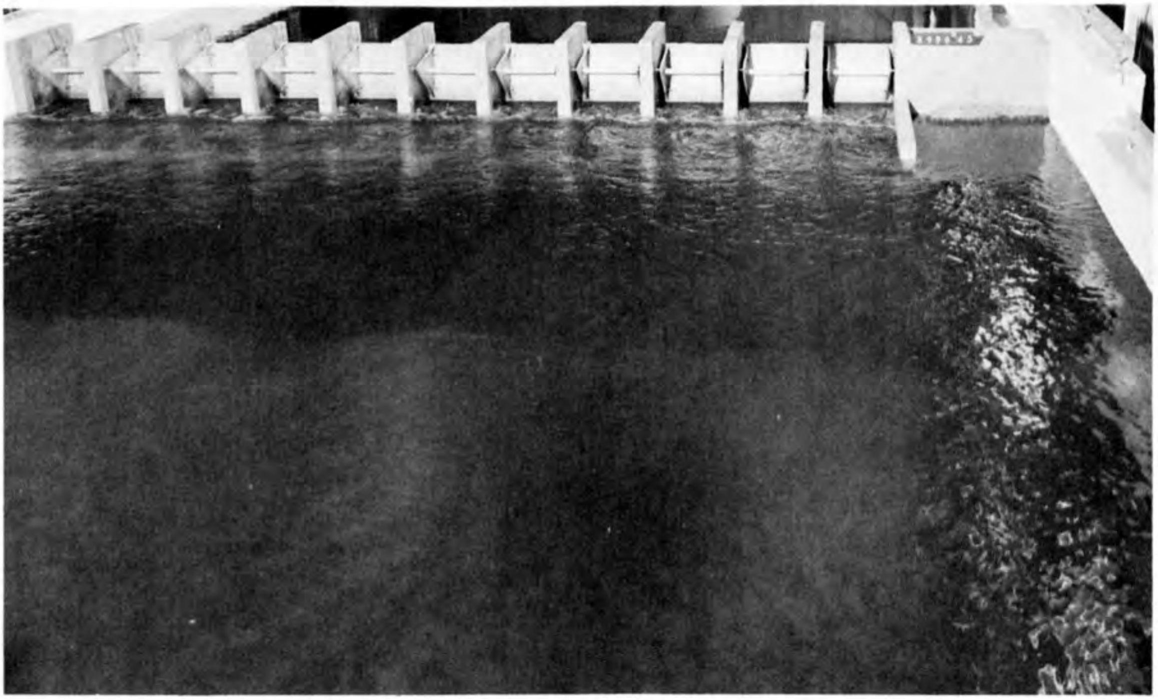


c. Type 16 stilling basin with four gates open 10 ft

Photo 10 (sheet 2 of 2)

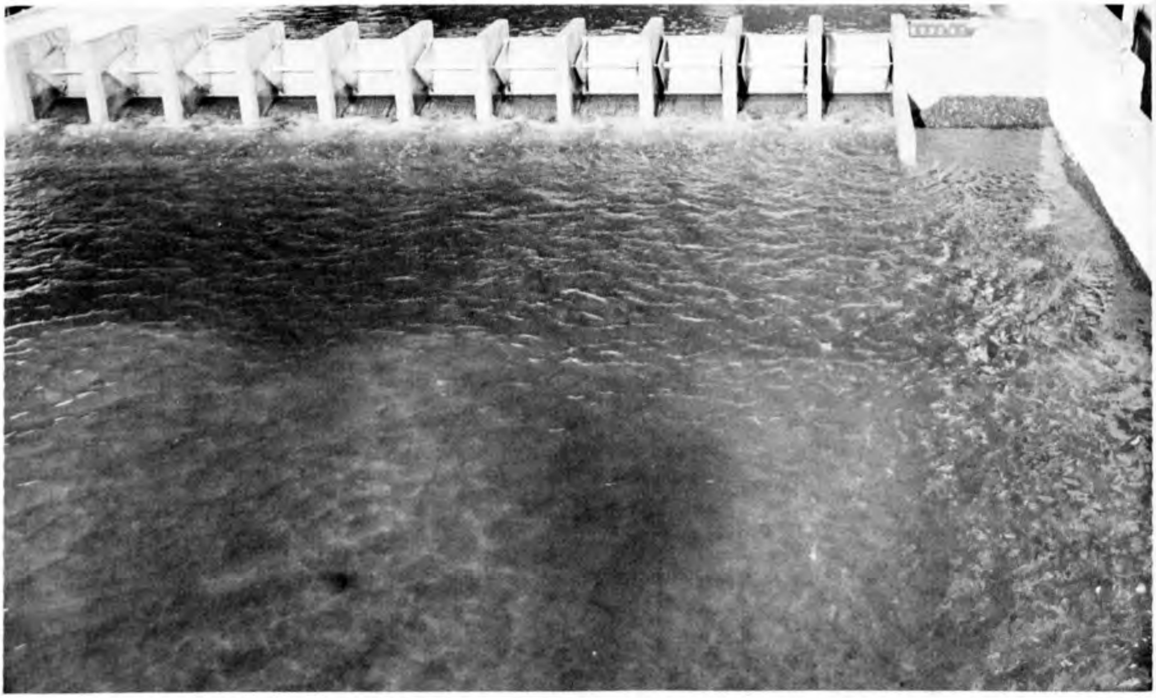


a. Tailwater elevation of 10.0

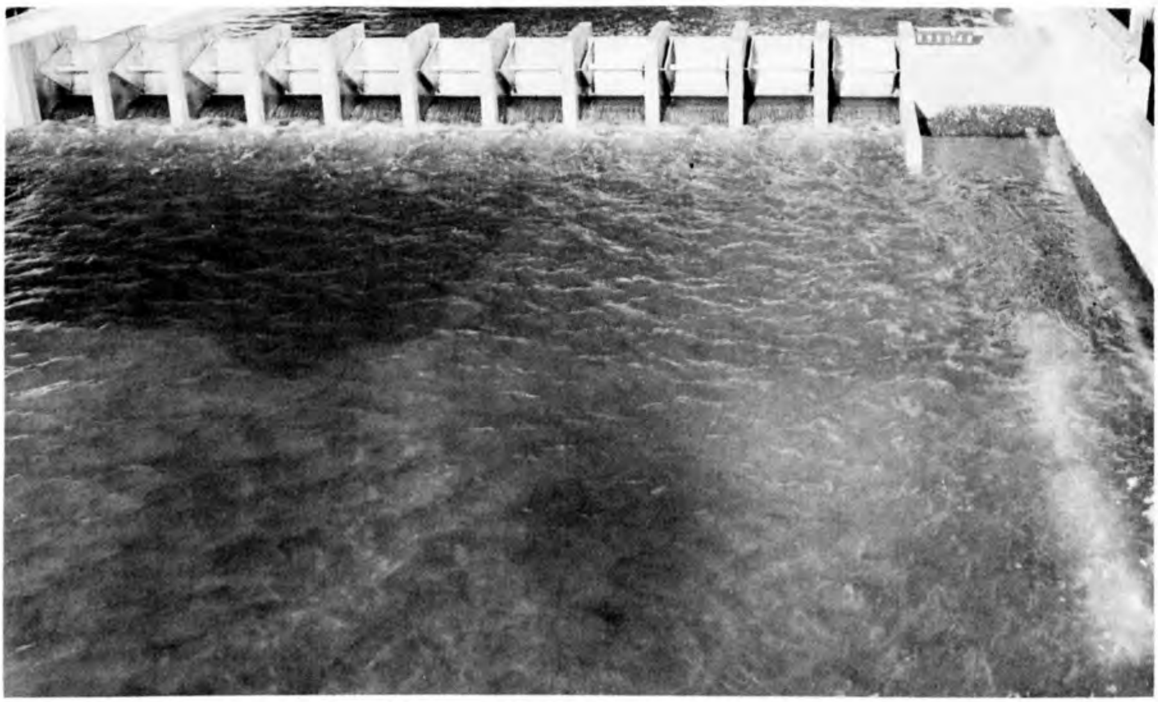


b. Tailwater elevation of 15.0

Photo 11. Flow conditions with multigate operation of type 17 stilling basin (without pier extensions) with 11 gates open 2 ft and pool elevations of 40.0 (sheet 1 of 2)

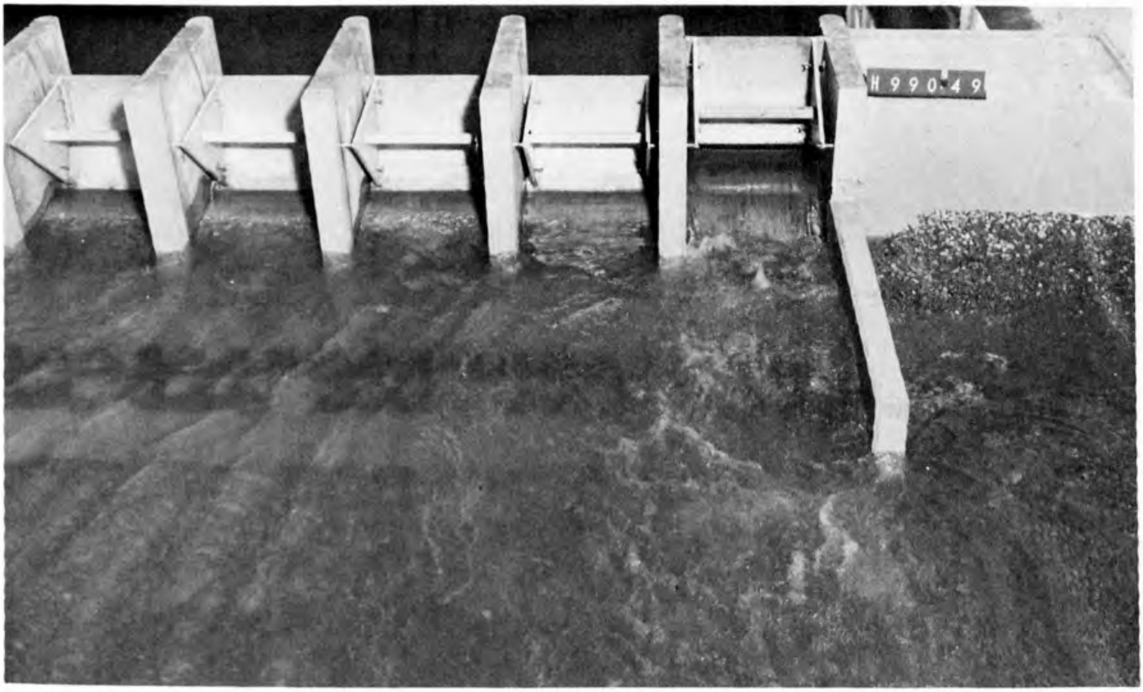


a. Eleven gates open 4 ft

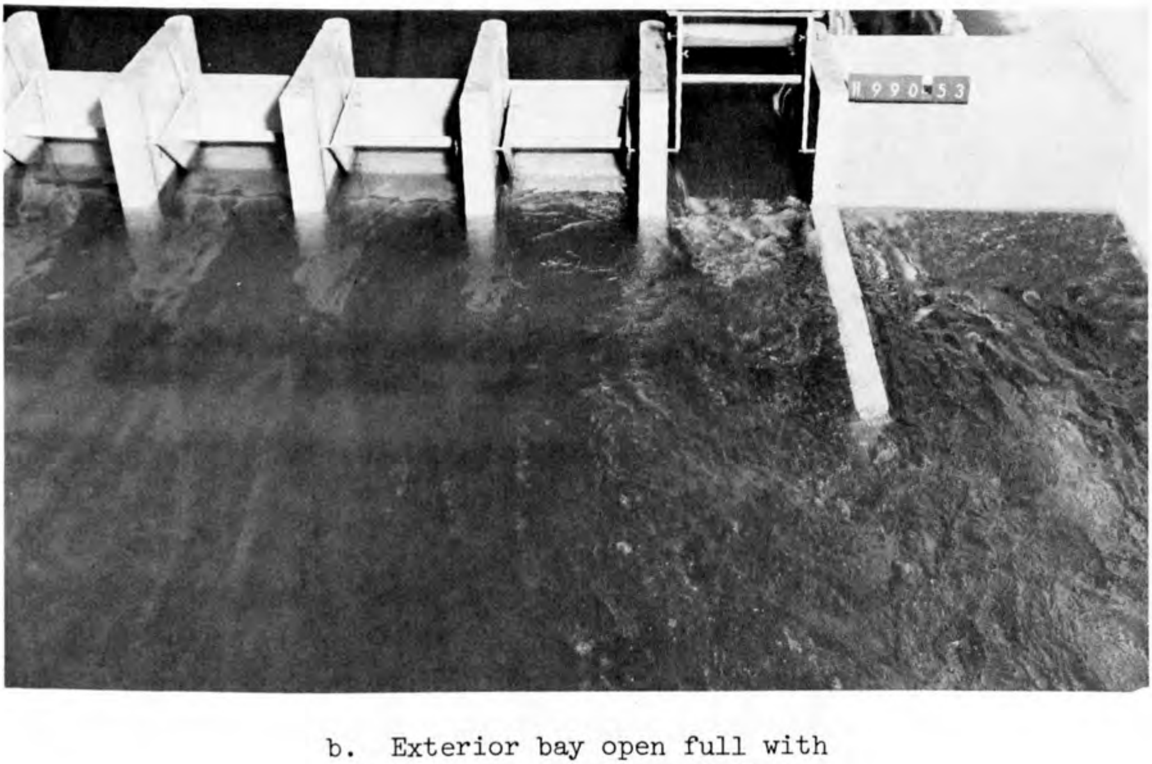


b. Eleven gates open 6 ft

Photo 12. Flow conditions with multigate operation of type 17 stilling basin (without pier extensions) with pool elevation of 40.0 and tailwater elevation of 10.0

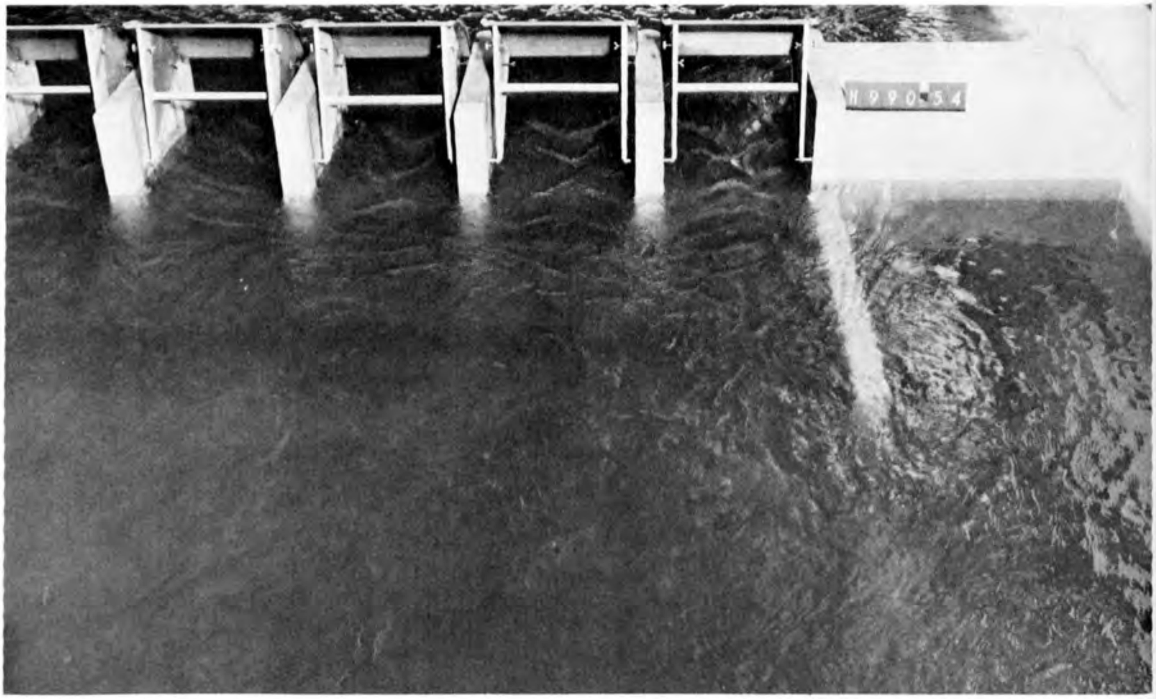


a. Exterior bay open one-half (14.5 ft) with tailwater elevation of 10.0

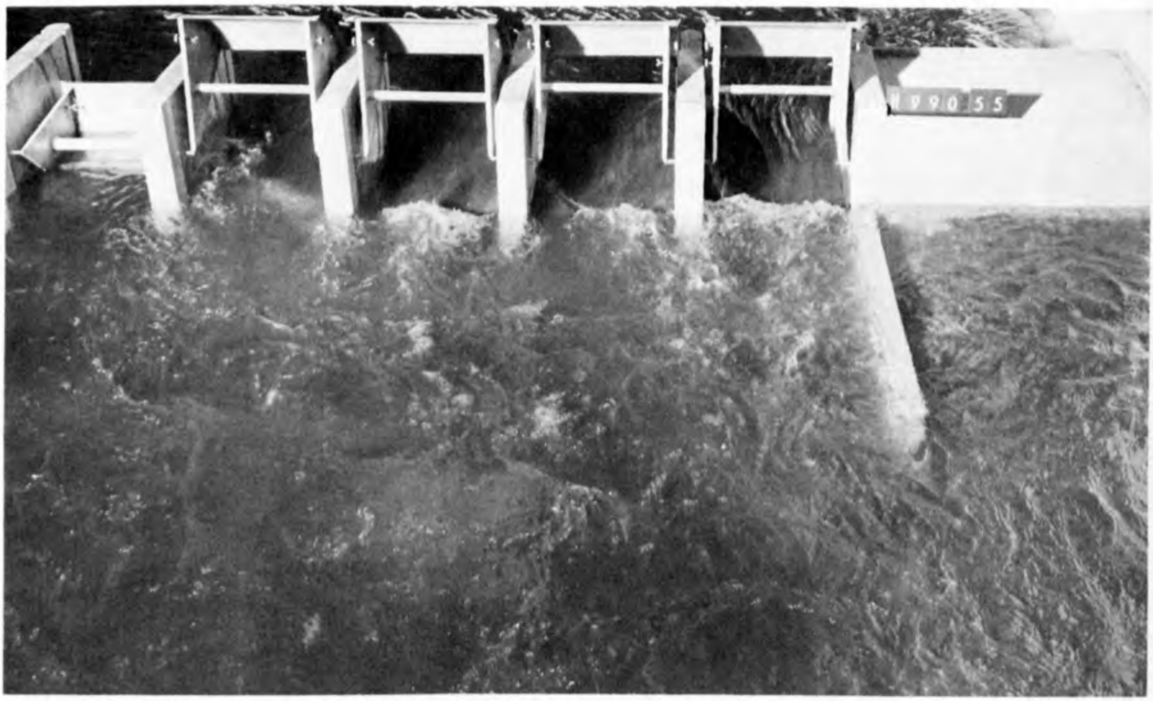


b. Exterior bay open full with tailwater elevation of 25.0

Photo 13. Flow conditions with single-gate operation of type 17 stilling basin (without pier extension) and proposed training wall, pool elevation of 40.0

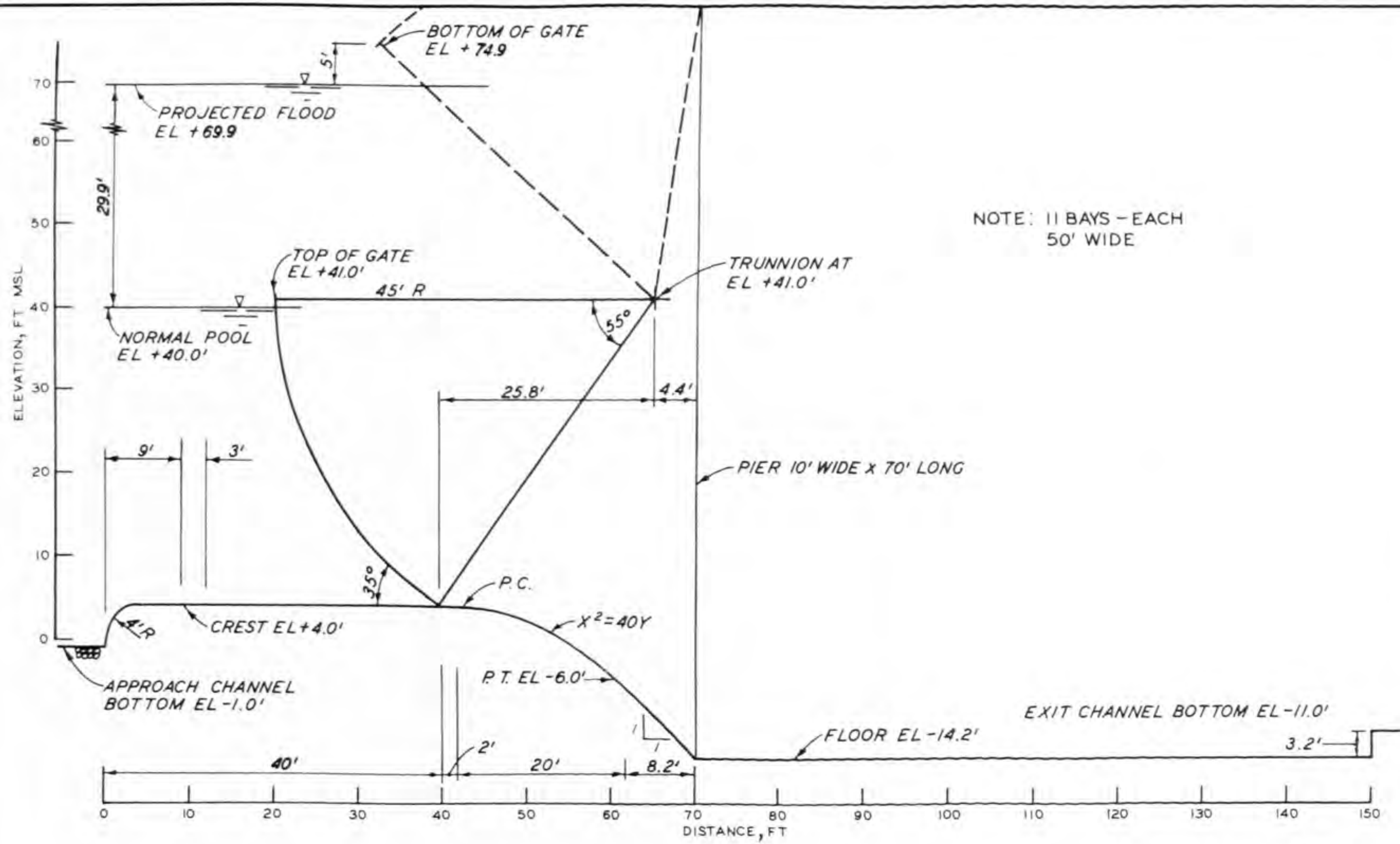


a. Five gates open full with tailwater elevation of 38.5

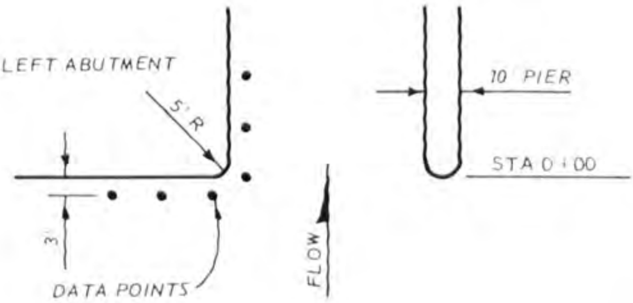


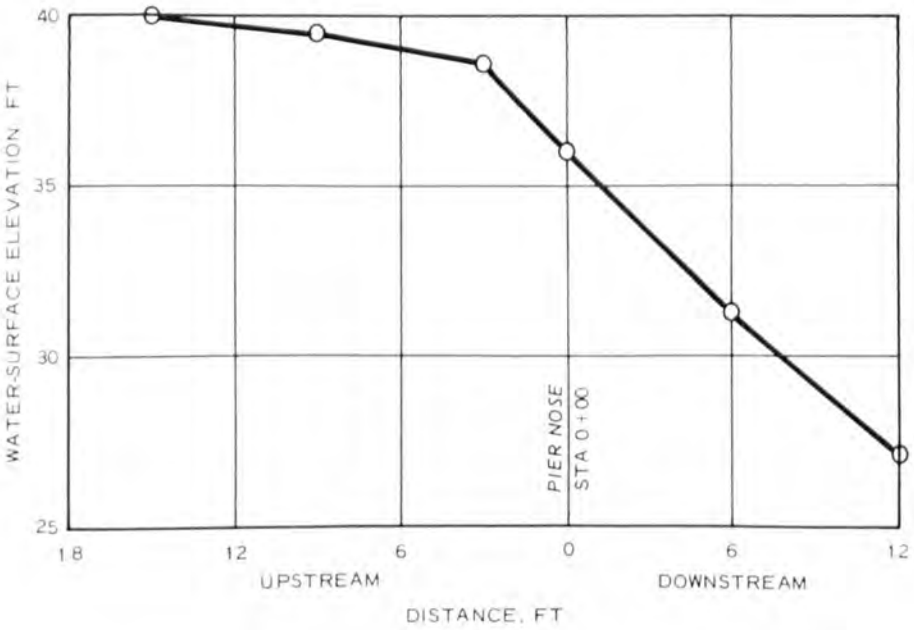
b. Four gates open full with tailwater elevation of 31.0

Photo 14. Flow conditions with multigate operation of type 17 stilling basin (without pier extensions) and proposed training wall with pool elevation of 40.0

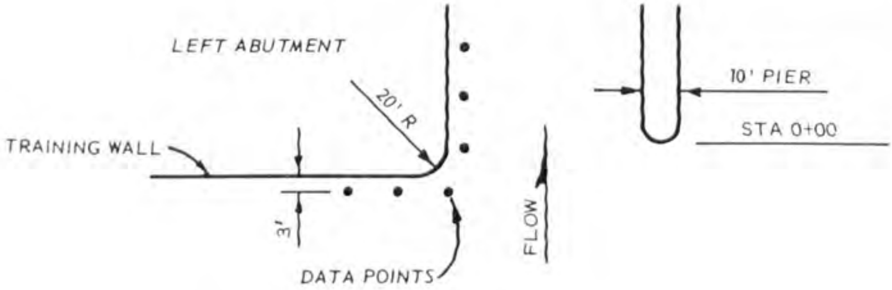


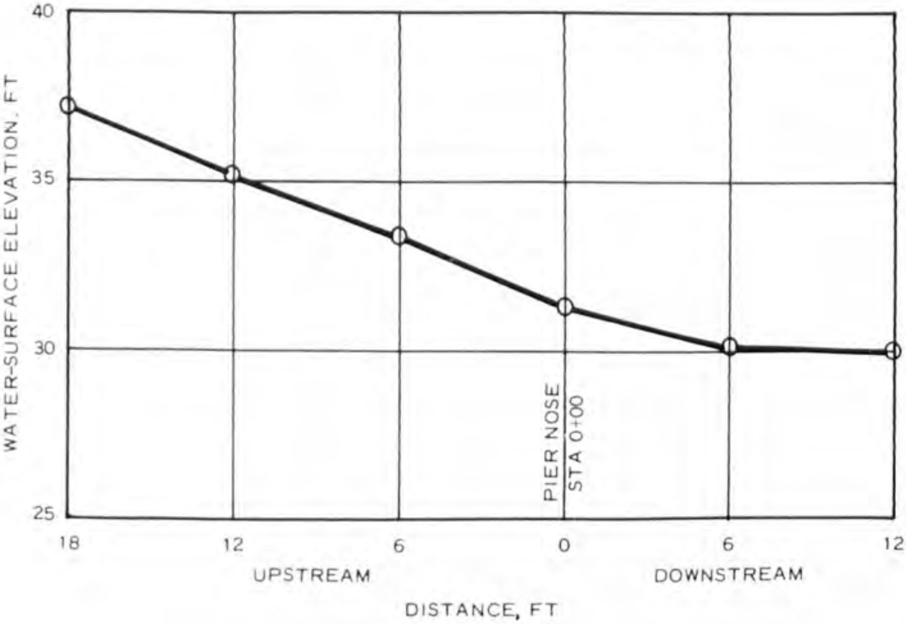
ORIGINAL DESIGN
STILLING BASIN



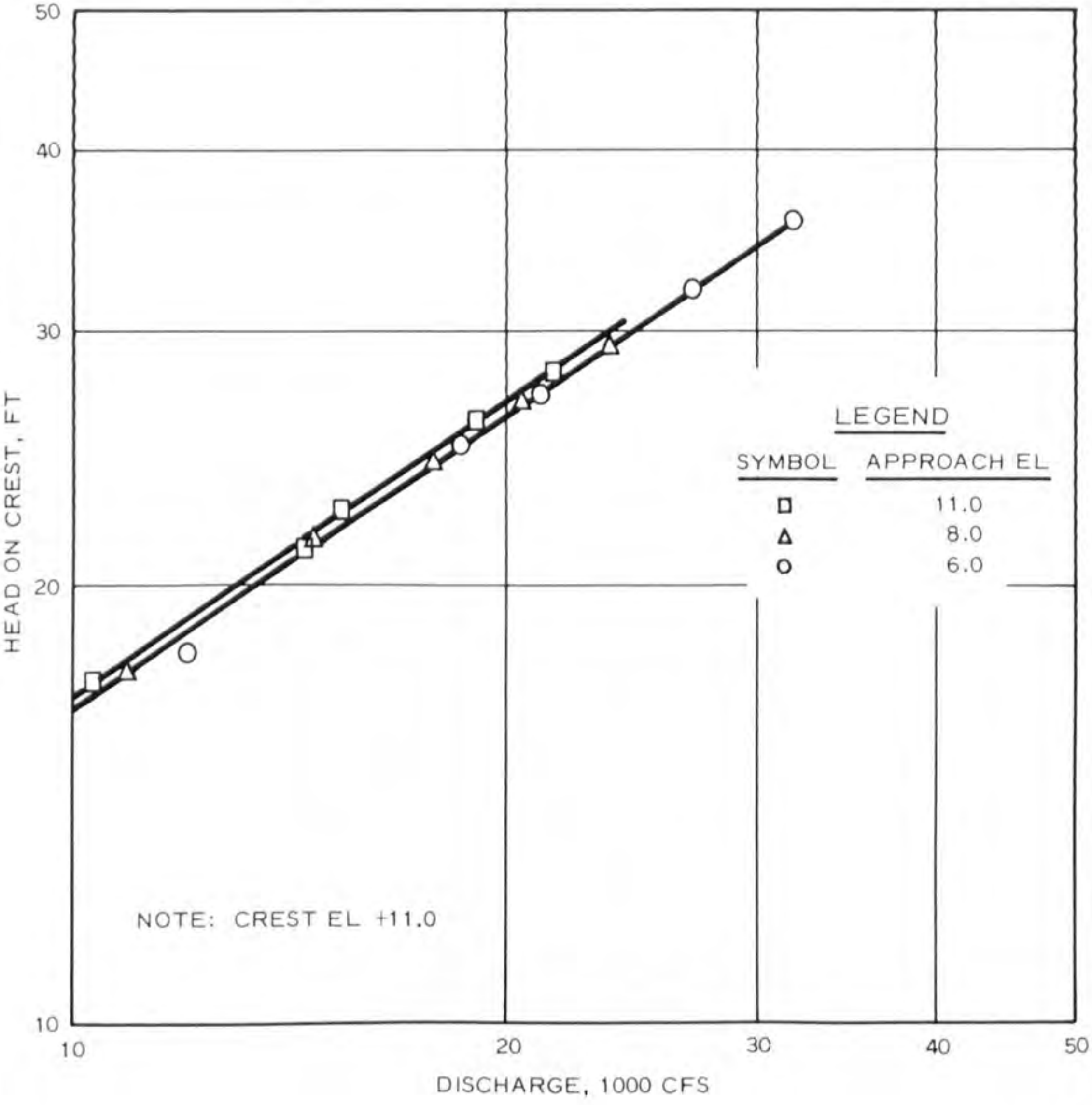


WATER-SURFACE PROFILE
5-FT RADIUS
LEFT ABUTMENT



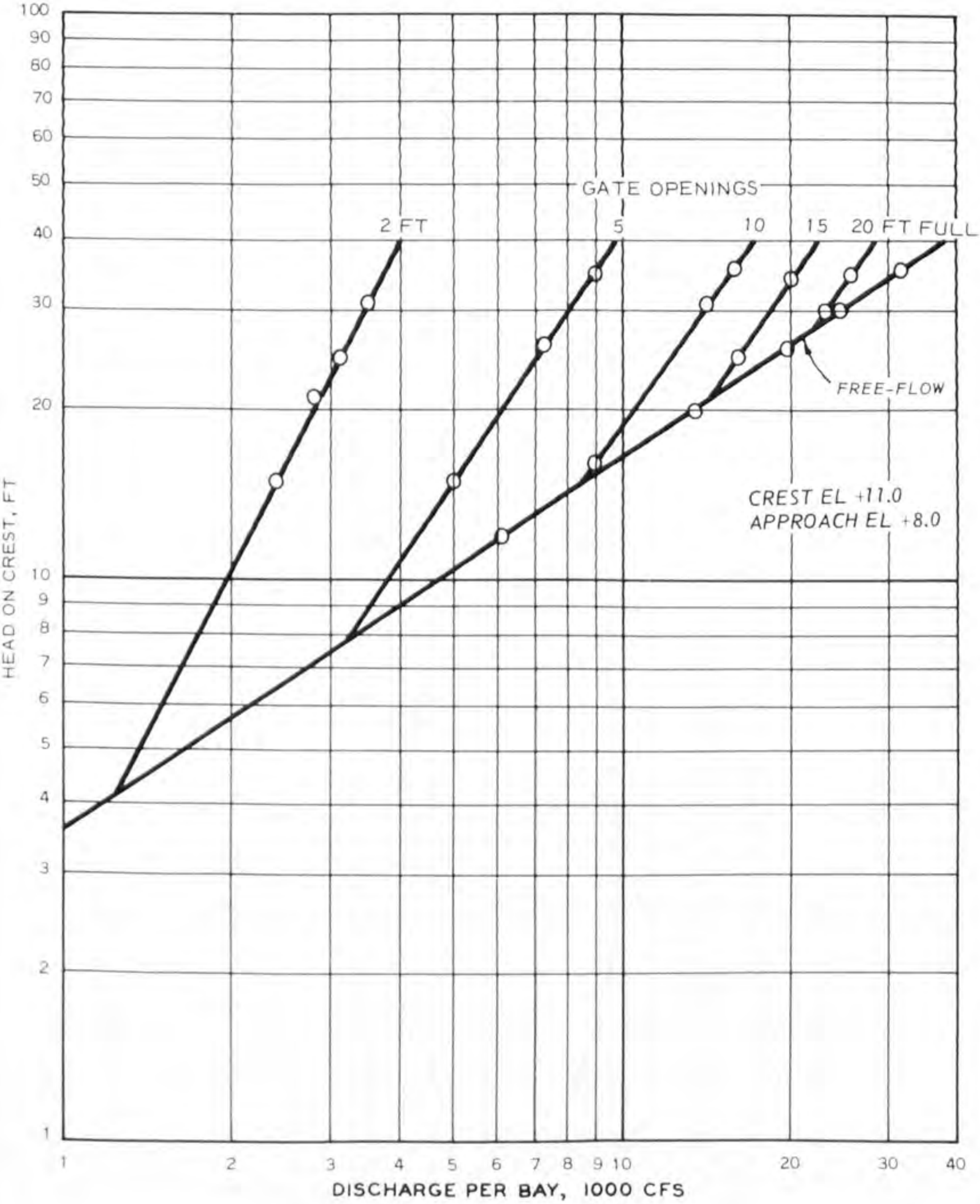


WATER-SURFACE PROFILE
20-FT RADIUS
LEFT ABUTMENT

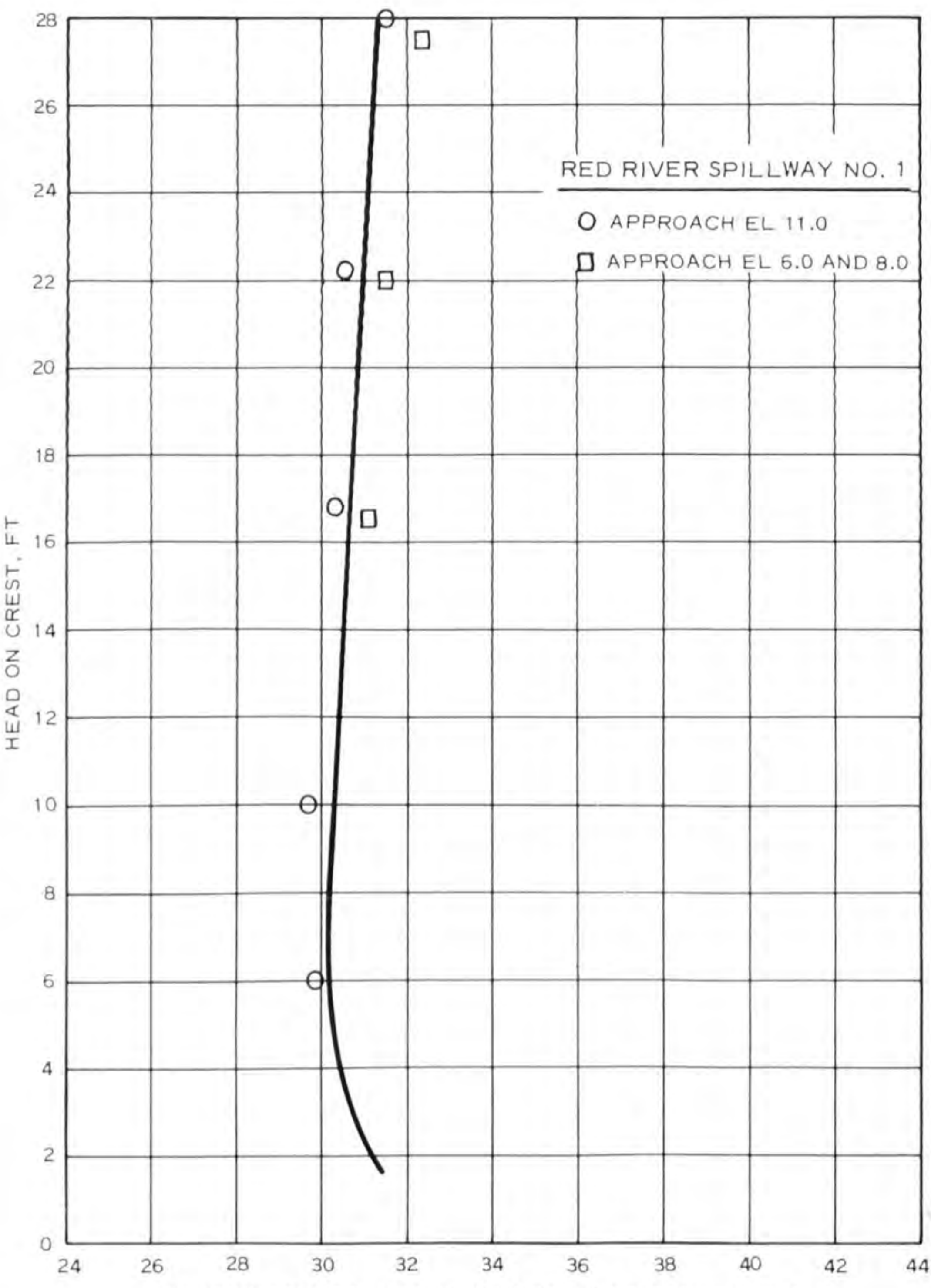


DISCHARGE VS HEAD

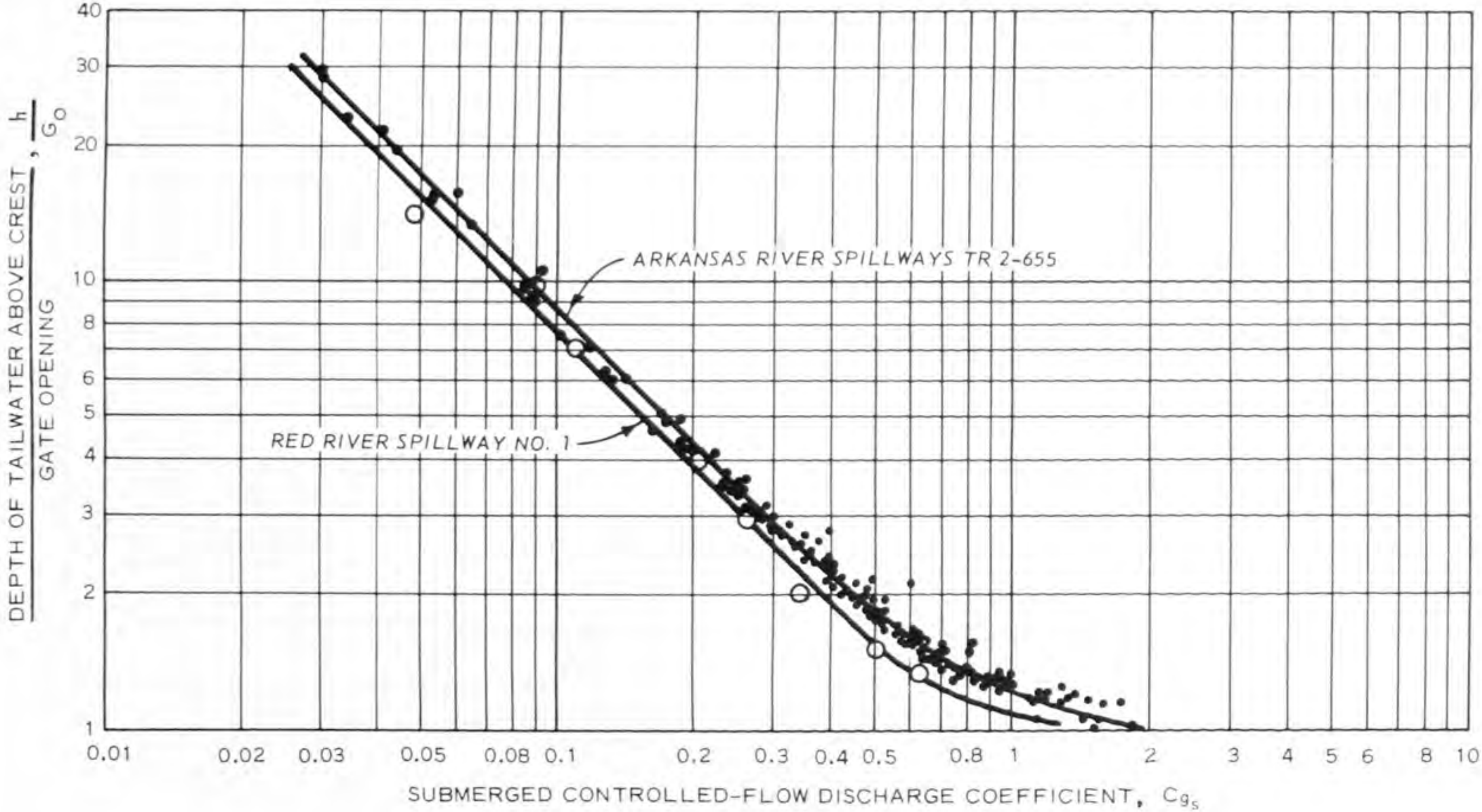
SINGLE GATE
FREE UNCONTROLLED FLOW



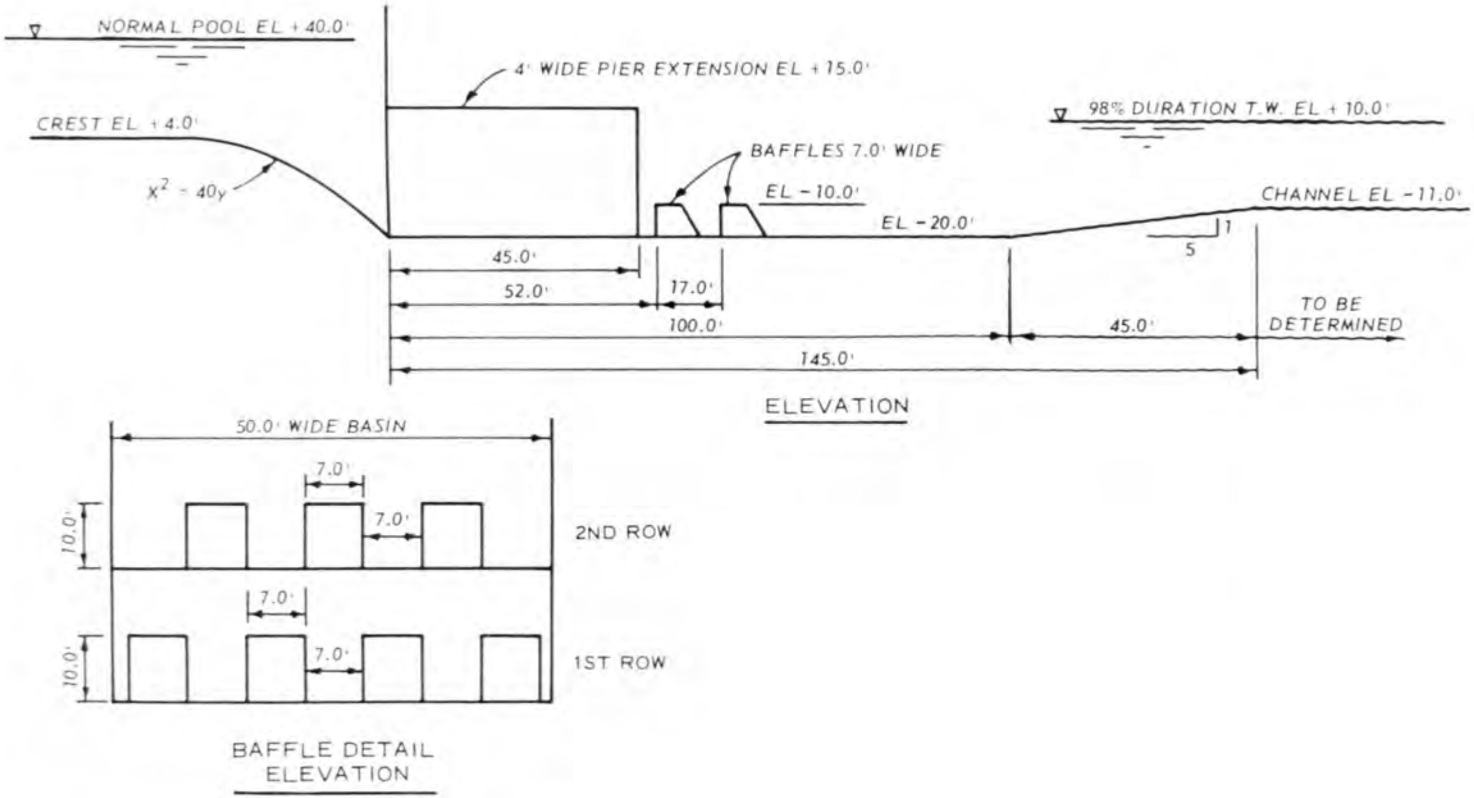
DISCHARGE VS HEAD
FREE FLOW



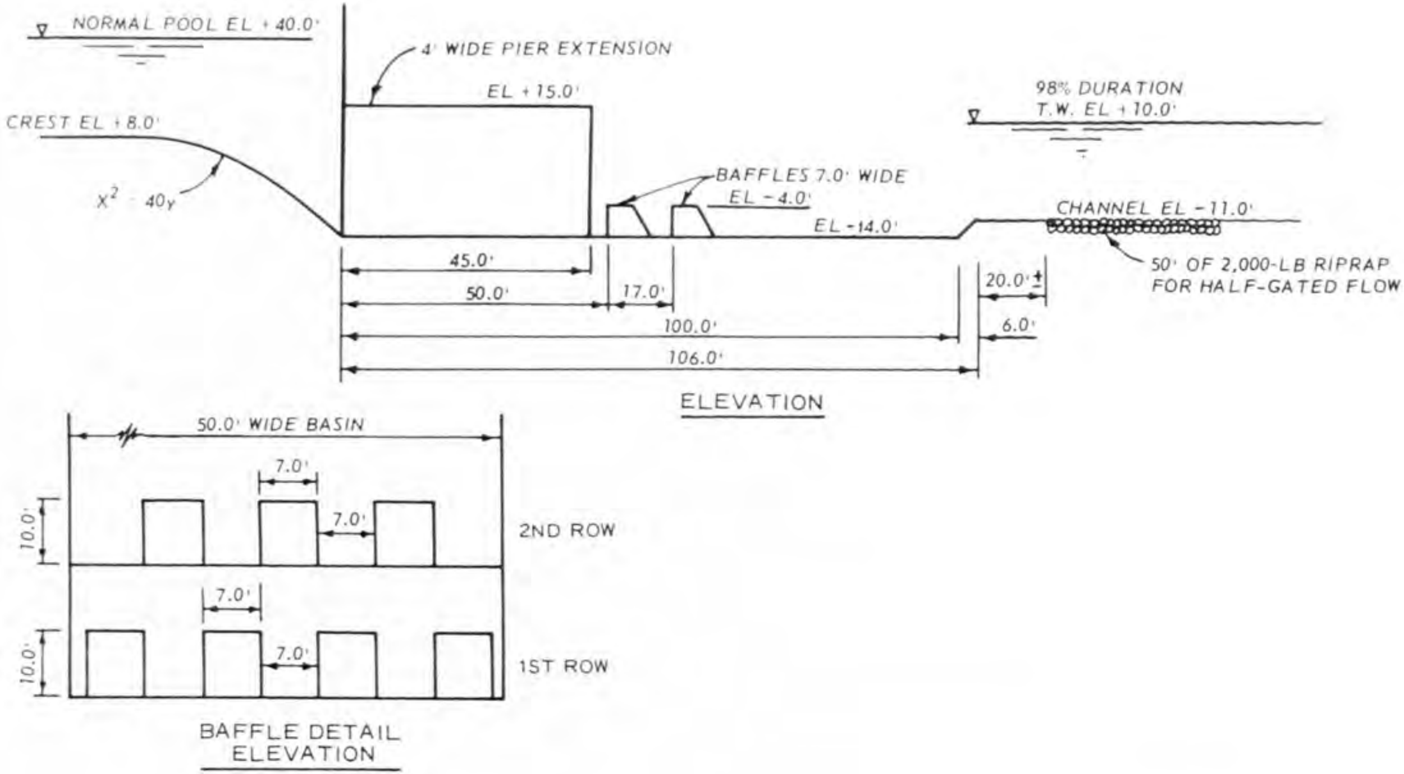
DISCHARGE COEFFICIENTS FOR
FREE UNCONTROLLED FLOW



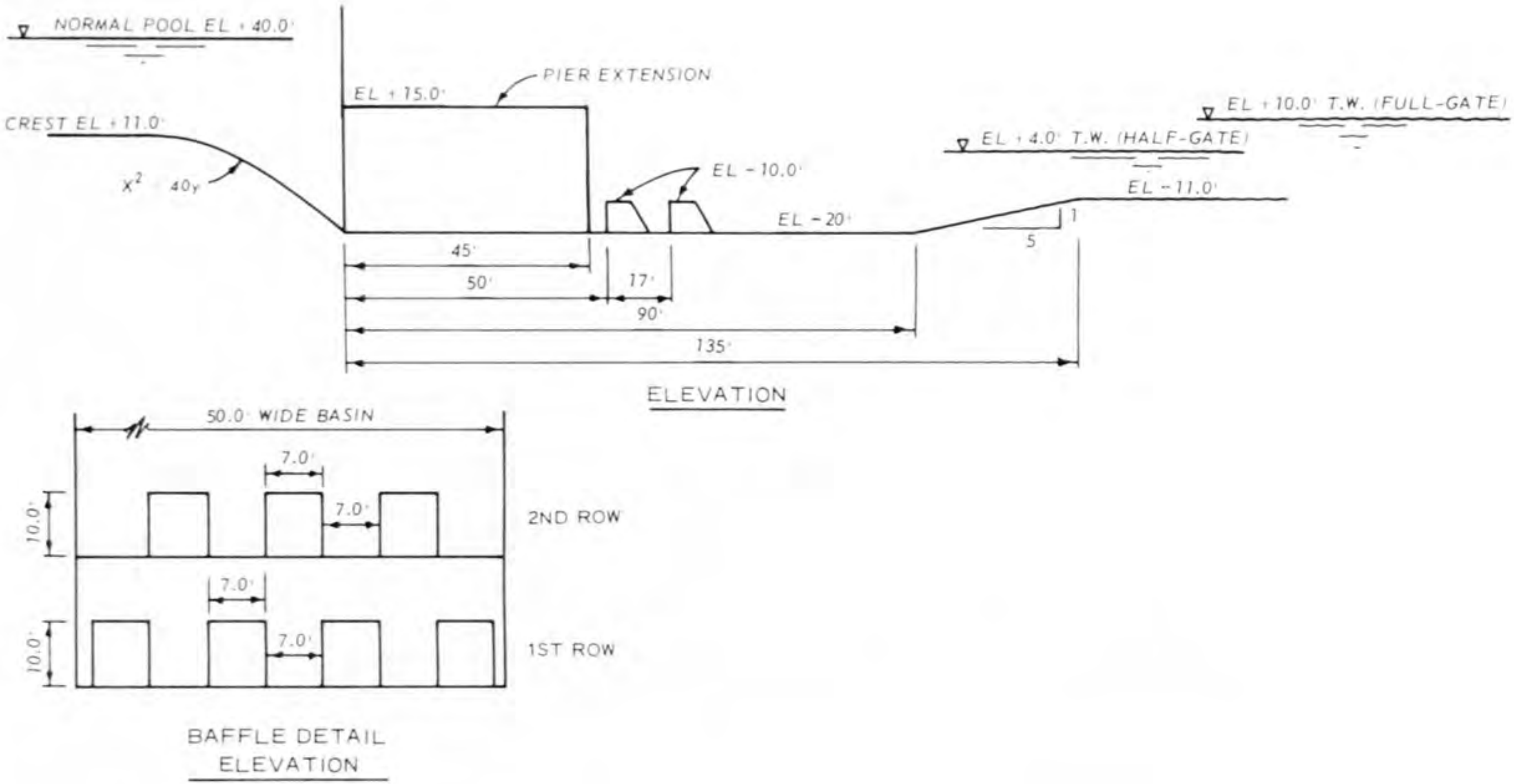
DISCHARGE COEFFICIENTS FOR
SUBMERGED CONTROLLED FLOW



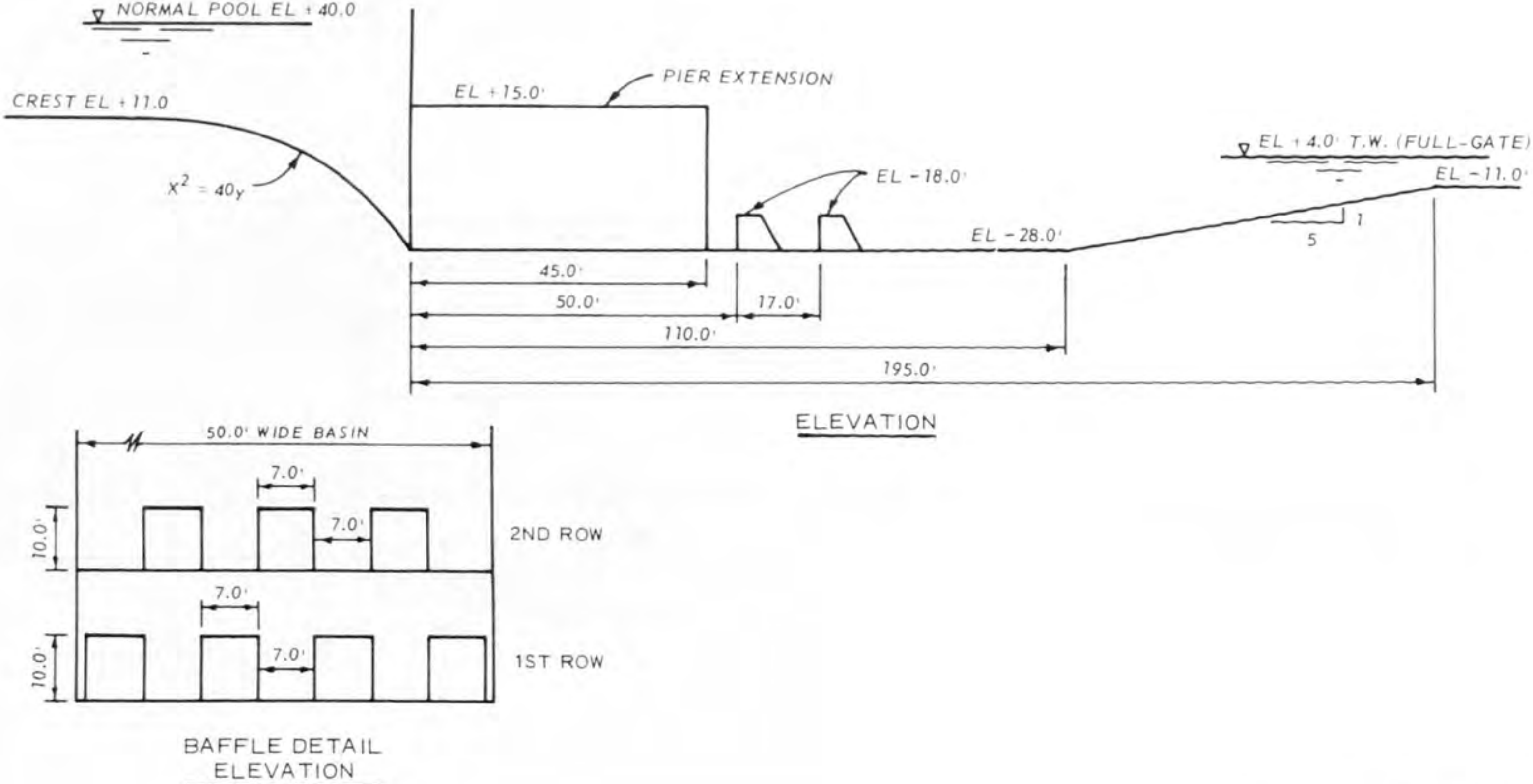
STILLING BASIN
TYPE 6



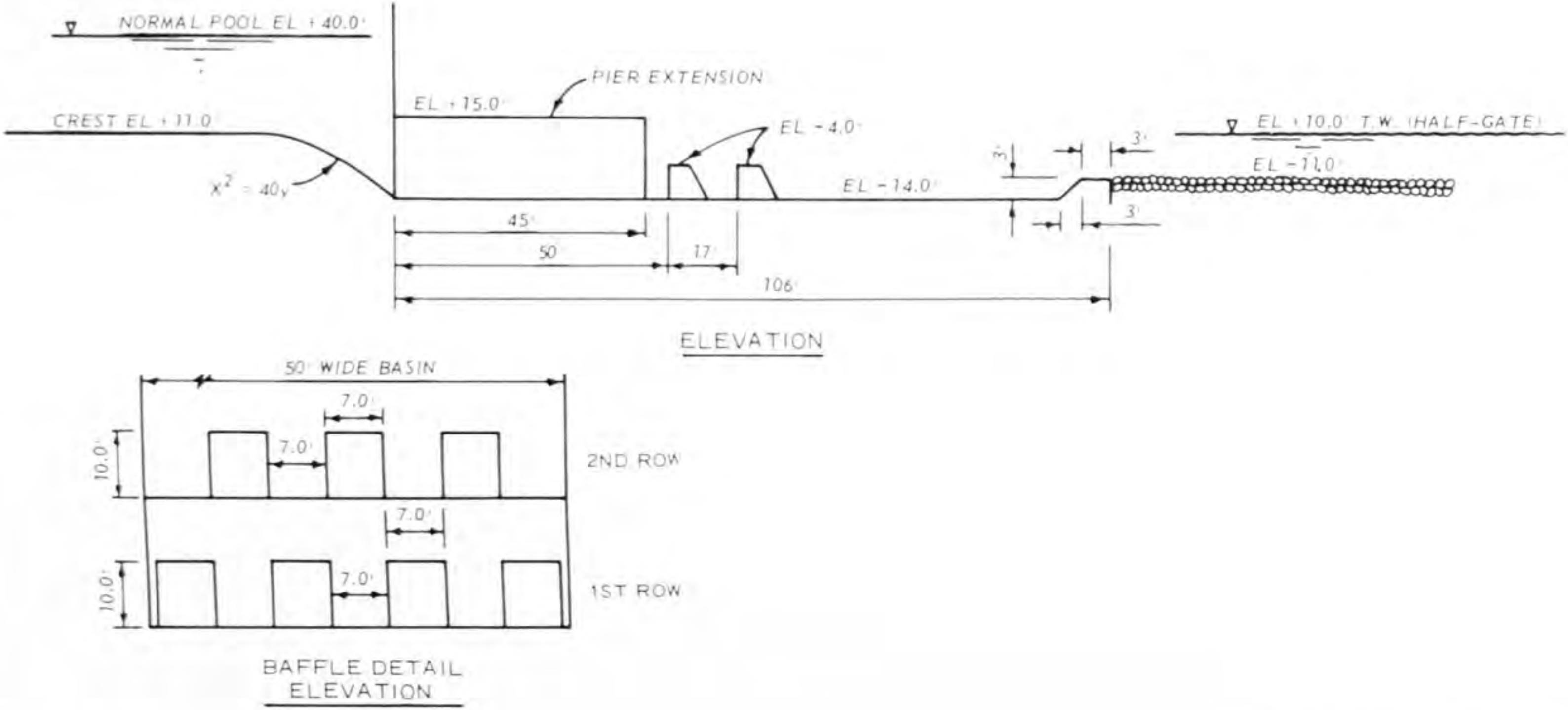
STILLING BASIN
TYPE 9



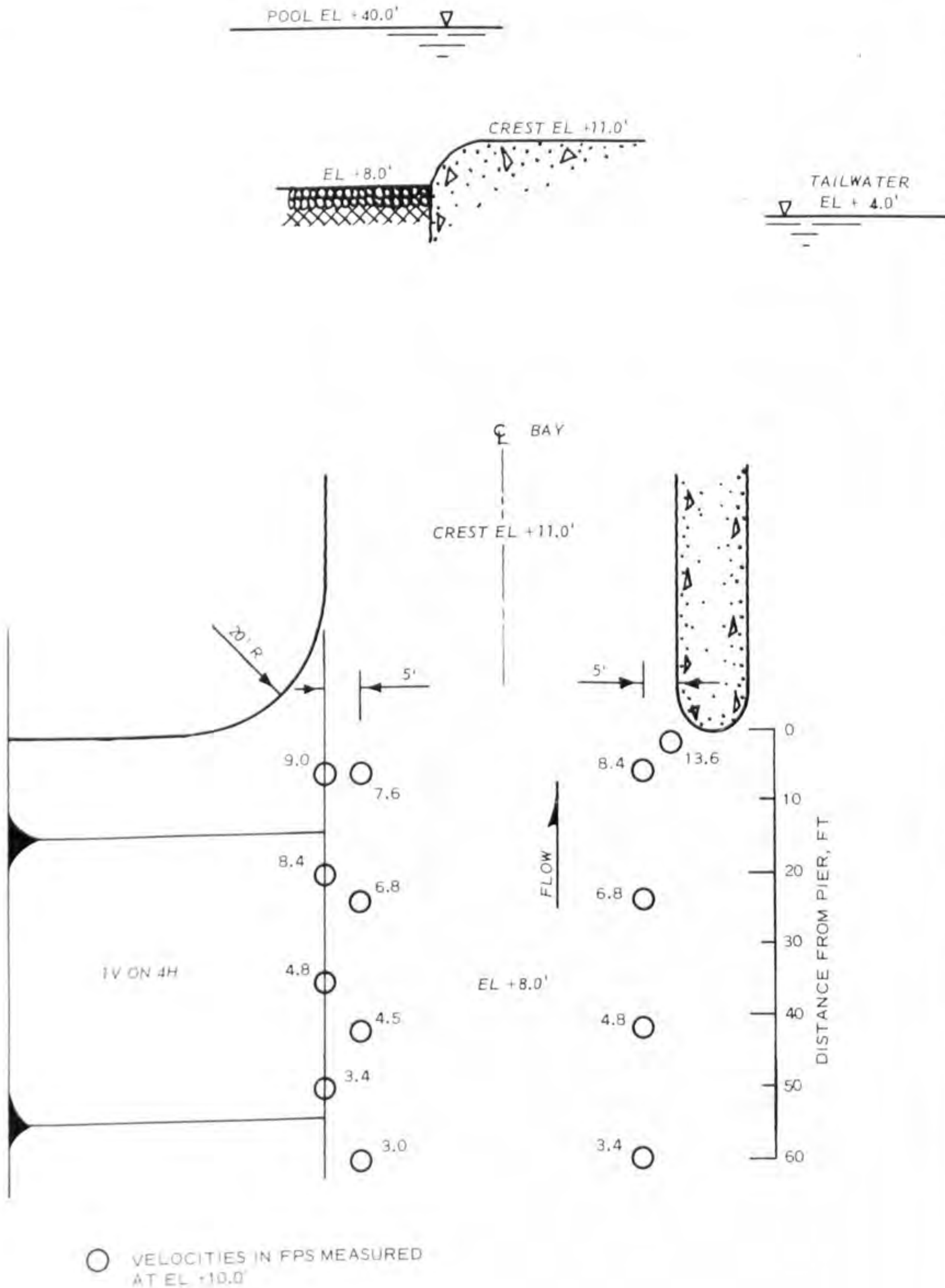
STILLING BASIN
TYPE 7



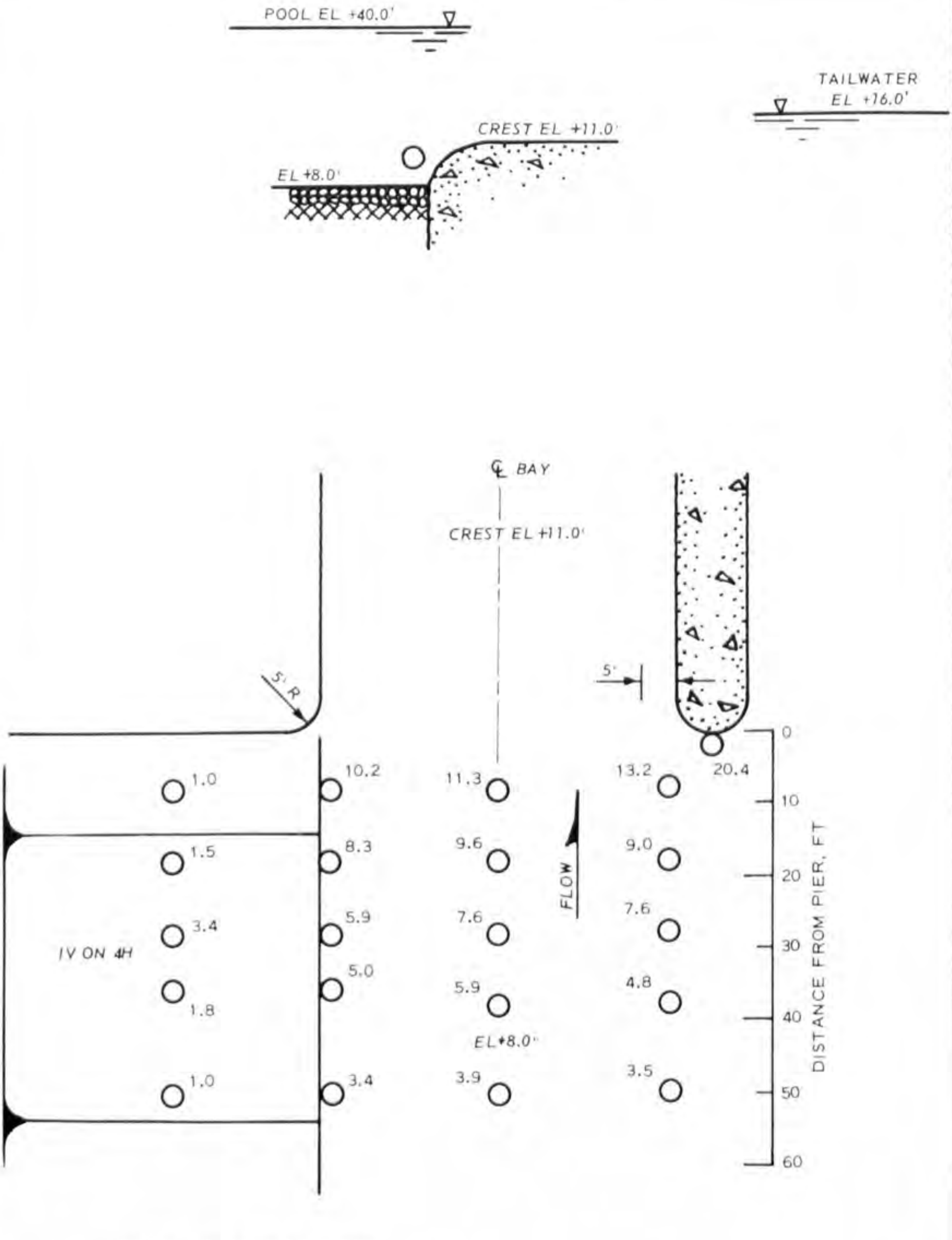
STILLING BASIN
TYPE 16



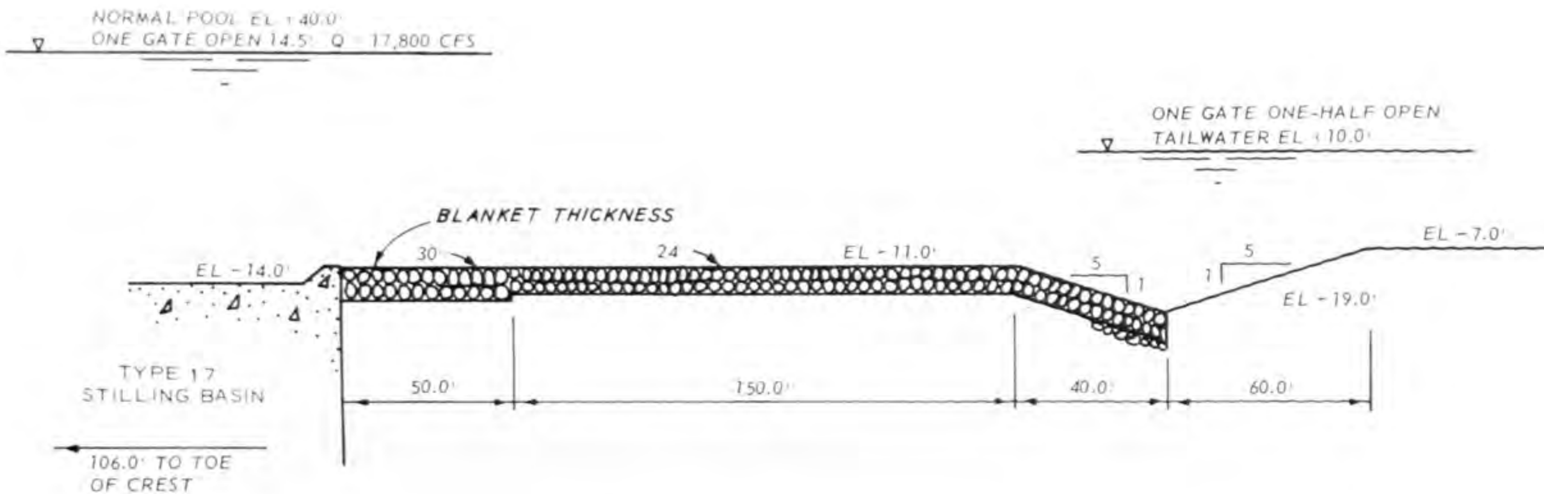
STILLING BASIN
TYPE 17



APPROACH VELOCITIES
ONE GATE ONE-HALF OPEN



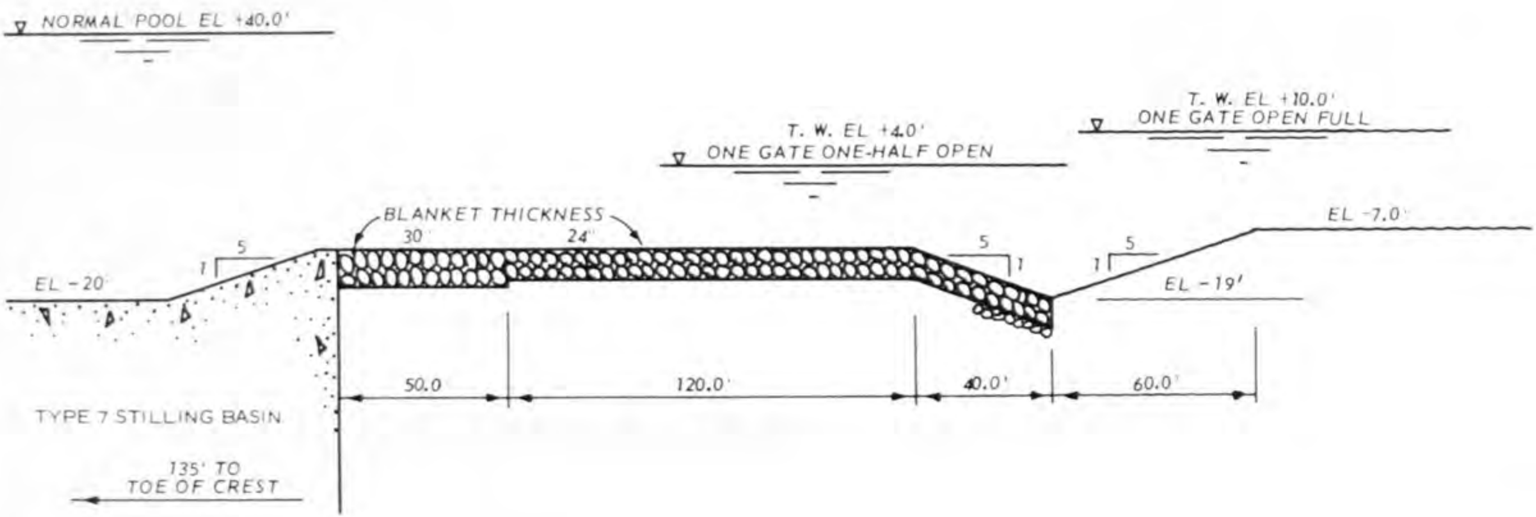
APPROACH VELOCITIES
ONE GATE FULLY OPEN



NOTE: CREST ELEVATION 11.0. RECOMMEND TOP OF RIPRAP BE 1 FT BELOW TOP OF END SILL.

RECOMMENDED MINIMUM RIPRAP REQUIREMENTS

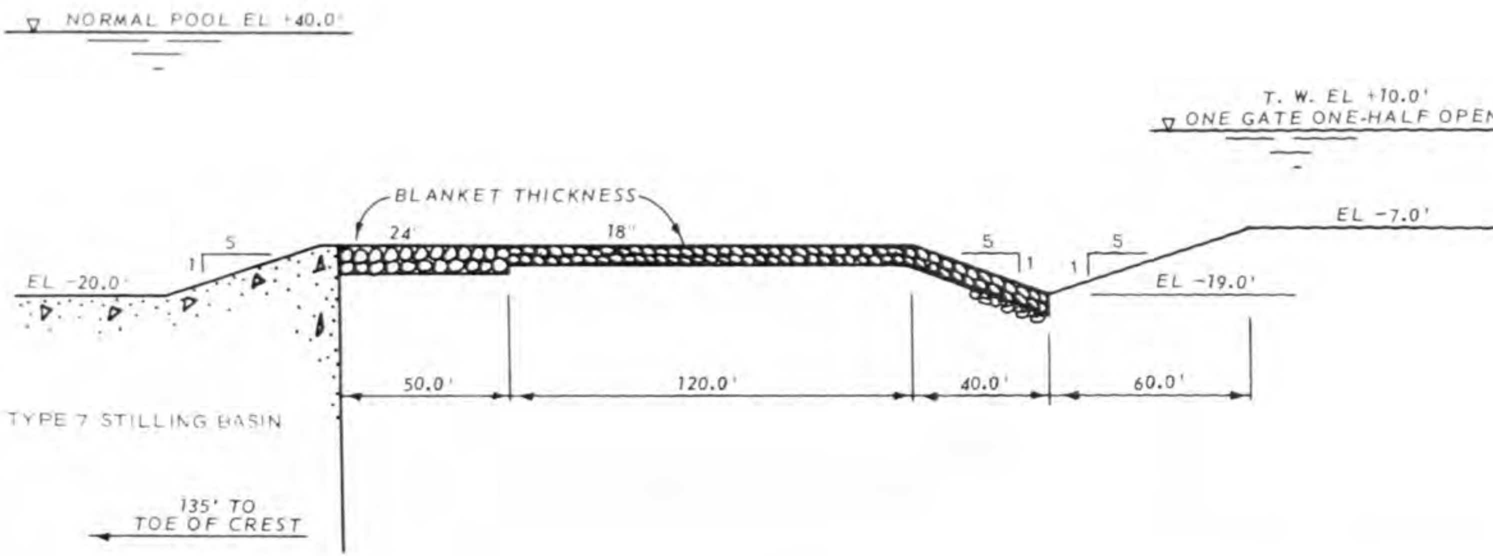
TYPE 17 STILLING BASIN
ONE GATE ONE-HALF OPEN
TAILWATER EL +10.0



NOTE: RECOMMEND TOP OF RIPRAP BE 1 FT BELOW TOP OF END SILL.

RECOMMENDED MINIMUM
RIPRAP REQUIREMENTS

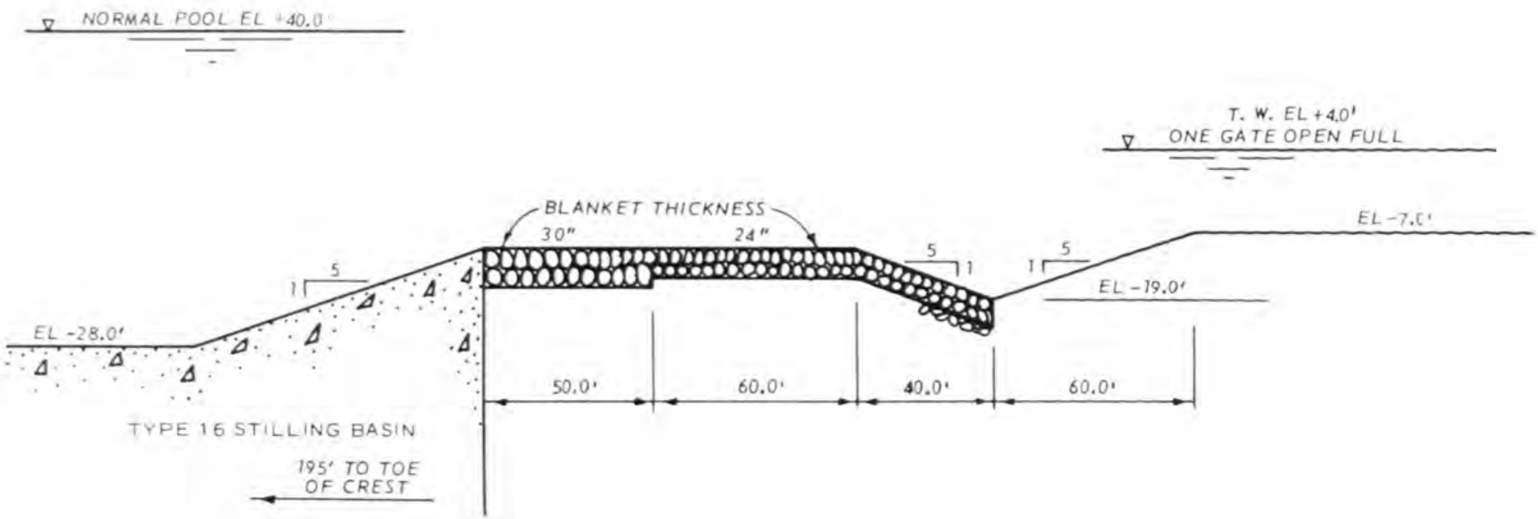
TYPE 7 STILLING BASIN
ONE GATE OPEN FULL
TAILWATER EL + 10.0



NOTE: RECOMMEND TOP OF RIPRAP BE 1 FT BELOW TOP OF END SILL.

RECOMMENDED MINIMUM RIPRAP REQUIREMENTS

TYPE 7 STILLING BASIN
ONE GATE ONE-HALF OPEN
TAILWATER EL +10.0



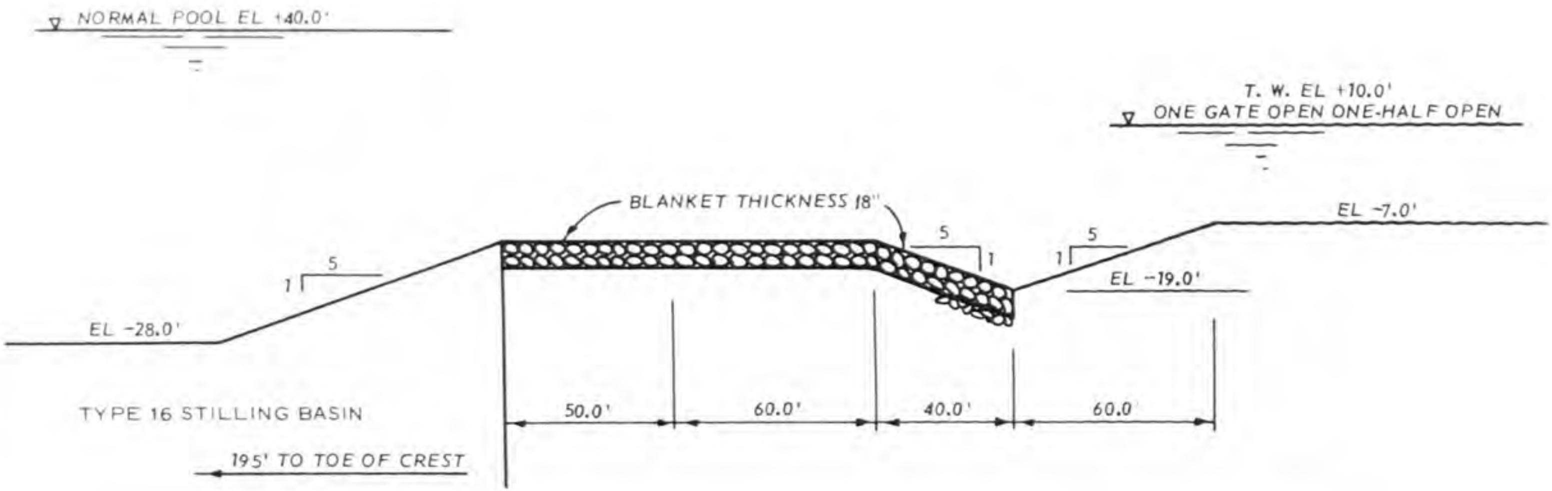
NOTE: RECOMMEND TOP OF RIPRAP BE 1 FT BELOW TOP OF END SILL.

RECOMMENDED MINIMUM RIPRAP REQUIREMENTS

TYPE 16 STILLING BASIN

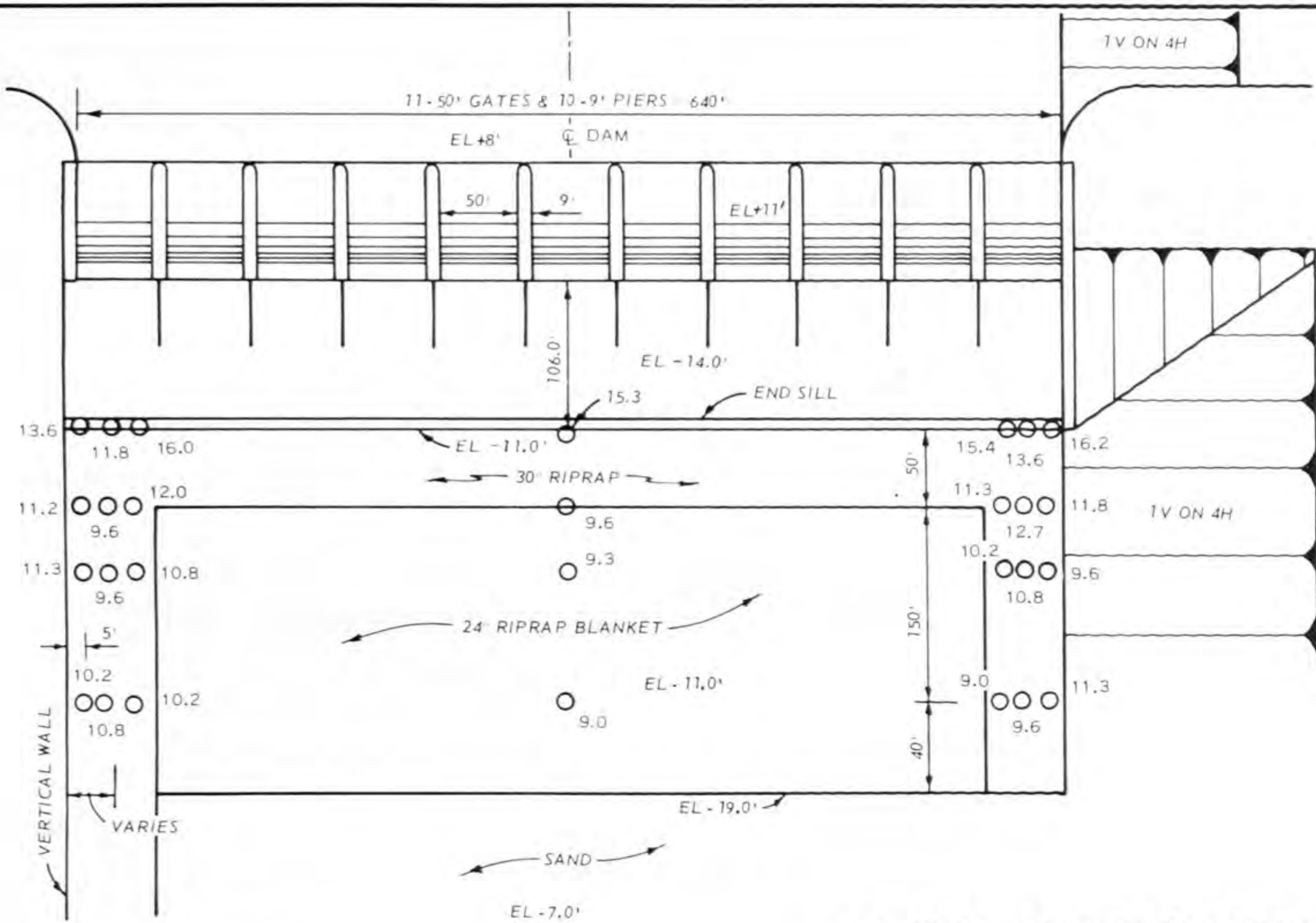
ONE GATE OPEN FULL

TAILWATER EL + 4.0



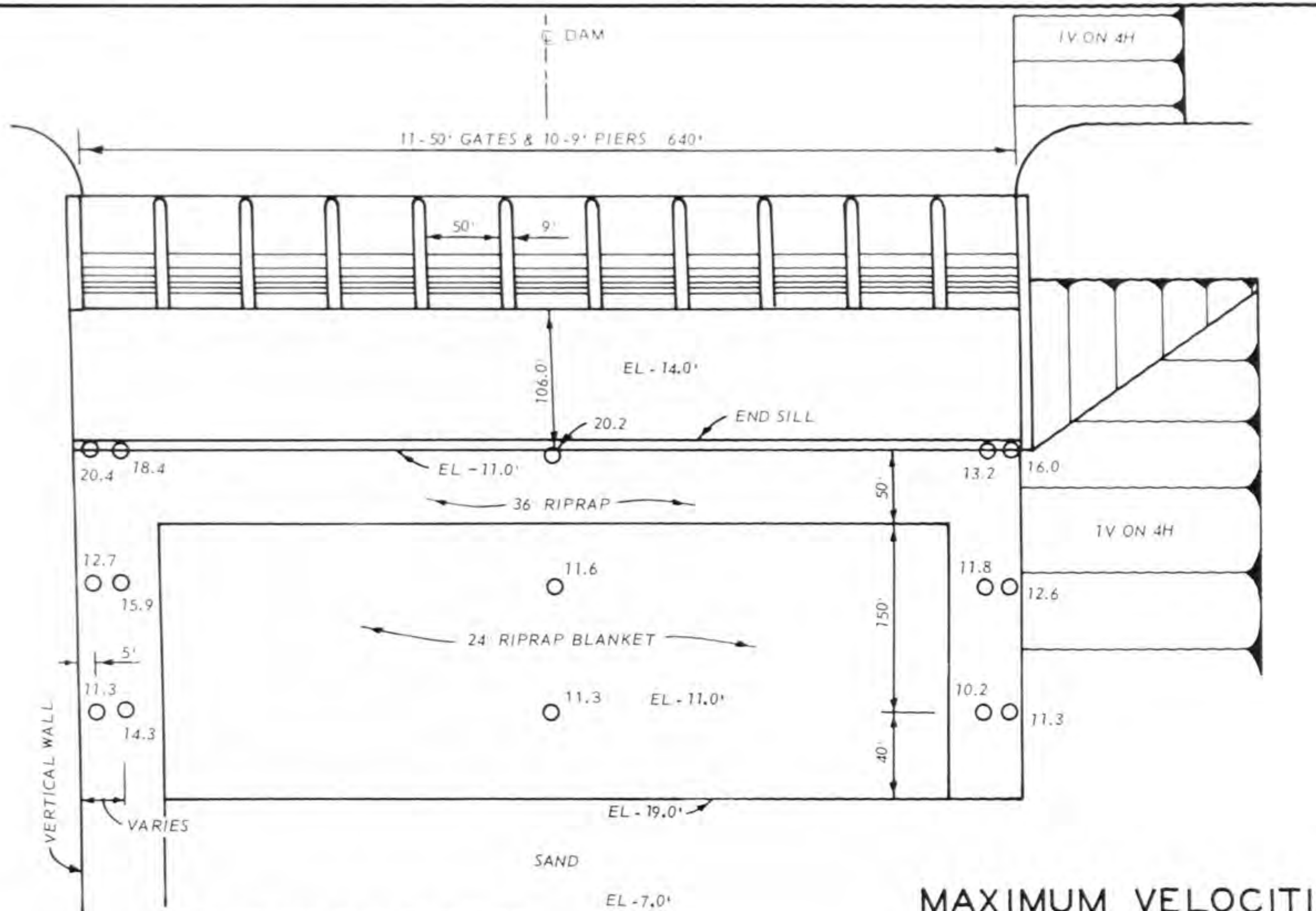
NOTE: RECOMMEND TOP OF RIPRAP BE 1 FT BELOW TOP OF END SILL.

RECOMMENDED MINIMUM RIPRAP REQUIREMENTS
TYPE 16 STILLING BASIN
ONE GATE ONE-HALF OPEN
TAILWATER EL +10.0



MAXIMUM VELOCITIES
WITH PIER EXTENSIONS

NOTE: VELOCITIES IN FPS
MEASURED 2 FT
ABOVE BOTTOM



NOTE: VELOCITIES IN FPS MEASURED 2 FT ABOVE BOTTOM.

MAXIMUM VELOCITIES
WITHOUT PIER EXTENSIONS